

March 2007

# DEFENSE ACQUISITIONS

## Key Decisions to Be Made on Future Combat System



G A O

Accountability \* Integrity \* Reliability

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>MAR 2007</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2007 to 00-00-2007</b>	
4. TITLE AND SUBTITLE <b>Defense Acquisitions. Key Decisions to Be Made on Future Combat System</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>U.S. Government Accountability Office, 441 G Street NW, Washington, DC, 20548</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES <b>66</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

GAO  
Accountability • Integrity • Reliability

# Highlights

Highlights of [GAO-07-376](#), a report to congressional committees

## Why GAO Did This Study

The Future Combat System (FCS) is central to Army transformation efforts, comprising 14 integrated weapon systems and an advanced information network. In previous work, GAO found that the elements of a sound business case—firm requirements, mature technologies, a knowledge-based acquisition strategy, a realistic cost estimate, and sufficient funding—were not present. As a result, FCS is considered high risk and in need of special oversight and review. Congress has mandated that the Department of Defense (DOD) decide in early 2009 whether FCS should continue.

GAO is required to review the program annually. In this report, GAO analyzes FCS development, including its requirements definition; status of critical technologies, software development, and complementary programs; soundness of its acquisition strategy related to design, production and spin-out of capabilities to current forces; and reasonableness of costs and sufficiency of funding.

## What GAO Recommends

GAO is making recommendations to the Secretary of Defense that specific criteria should be considered during the 2009 milestone review and alternatives to the program analyzed should FCS fail to deliver needed capabilities when and as expected. DOD concurred with GAO's recommendations.

[www.gao.gov/cgi-bin/getrpt?GAO-07-376](http://www.gao.gov/cgi-bin/getrpt?GAO-07-376).

To view the full product, including the scope and methodology, click on the link above. For more information, contact Paul Francis, 202-512-4841, [francispa@gao.gov](mailto:francispa@gao.gov).

## DEFENSE ACQUISITIONS

# Key Decisions to Be Made on Future Combat System

## What GAO Found

The Army has been granted a lot of latitude to carry out a large program like FCS this far into development with relatively little demonstrated knowledge. Tangible progress has been made during the year in several areas, including requirements and technology. Such progress warrants recognition, but confidence that the program can deliver as promised depends on high levels of demonstrated knowledge, which are yet to come. Following the preliminary design review in 2009, there should be enough knowledge to demonstrate the soundness of the FCS business case. If significant doubts remain about the program's executability at that time, DOD will have to consider alternatives to proceeding with the program. Currently, GAO sees the FCS business case as follows:

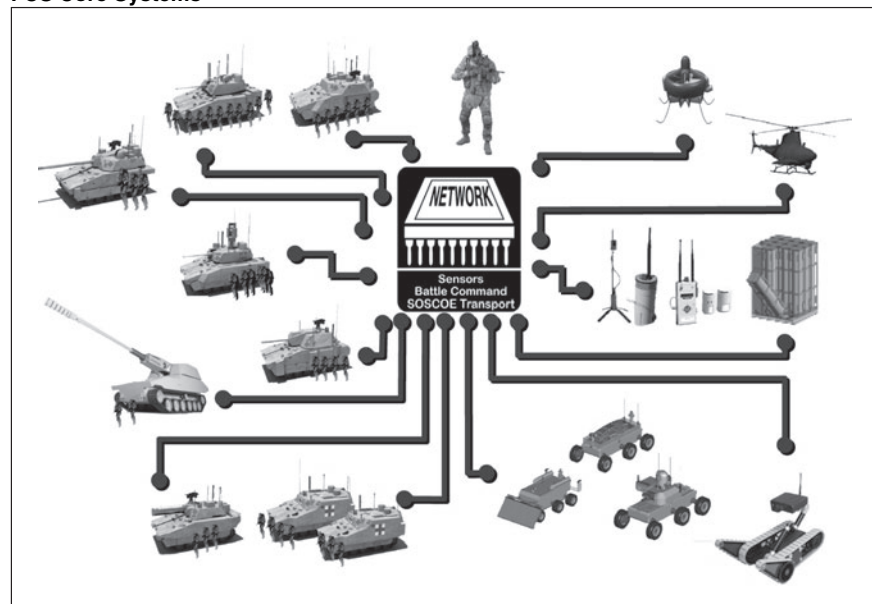
**Requirements.** Progress has been made in defining requirements and making some difficult trade-offs, but key assumptions about the performance of immature technologies and other technical risks remain to be proven.

**Technology.** The Army has made progress in maturing technologies, but it will take several more years to reach full maturity. All key technologies should have been mature in 2003 when the program began. FCS software has doubled in size compared to original estimates and faces significant risks. The Army is attempting a disciplined approach to managing software development.

**Acquisition Strategy.** The FCS acquisition strategy is compressed. Key testing to demonstrate FCS performance will not be completed, and maturity of design and production will not be demonstrated until after the production decision.

**Program Costs.** New estimates place FCS costs significantly above the current estimate of \$163.7 billion. The Army has recently proposed a plan to buy fewer systems and slow production rates. This recent program adjustment will affect program costs, but details are not yet available.

### FCS Core Systems



Source: U.S. Army.

---

# Contents

---

<b>Letter</b>		<b>1</b>
	Results in Brief	2
	Background	3
	Despite Progress, FCS Requirements Must Still Prove Technically Feasible and Affordable	10
	Army Reports Significant Progress, but Major Technological Challenges Remain	18
	Concurrent Acquisition Strategy Will Provide for Late Demonstration of FCS Capabilities	30
	Likely Growth of FCS Costs Increases Tension between Program Scope and Available Funds	40
	Conclusions	47
	Agency Comments and Our Evaluation	49
<b>Appendix I</b>	<b>Scope and Methodology</b>	<b>52</b>
<b>Appendix II</b>	<b>Comments from the Department of Defense</b>	<b>53</b>
<b>Appendix III</b>	<b>Technology Readiness Levels</b>	<b>56</b>
<b>Appendix IV</b>	<b>Technology Readiness Level Ratings</b>	<b>58</b>
<b>Related GAO Products</b>		<b>60</b>

---

## Tables

Table 1: FCS Software Blocks, Percentage of Completion, and Delivery Dates	28
Table 2: Key FCS Test Event Schedule	35
Table 3: Comparison of the Original Cost Estimate and Recent Cost Estimates for the FCS Program (in billions of dollars)	41
Table 4: Annual and Cumulative FCS Funding and Planned Events and Achievements	43
Table 5: Technology Readiness Level Descriptions	56

---

## Figures

Figure 1: FCS's Core Systems	5
Figure 2: Flow of FCS's Overarching Requirements to System-Level Requirements	11
Figure 3: TRL 6 Projections over Time	19
Figure 4: FCS Projected Software Lines of Code (in thousands)	27
Figure 5: Acquisition Compared with Commercial Best Practices	32

---

## Abbreviations

DOD	Department of Defense
FCS	Future Combat System
JTRS	Joint Tactical Radio System
TG	Terminal Guidance
TRL	Technology Readiness Level
WIN-T	Warfighter Information Network-Tactical

This is a work of the U.S. government and is not subject to copyright protection in the United States. It may be reproduced and distributed in its entirety without further permission from GAO. However, because this work may contain copyrighted images or other material, permission from the copyright holder may be necessary if you wish to reproduce this material separately.



United States Government Accountability Office  
Washington, DC 20548

March 15, 2007

## Congressional Committees

As the centerpiece of the Army's transformation to a lighter, more agile, and more capable combat force, the Future Combat System (FCS) program—which comprises 14 integrated weapon systems and an advanced information network needed for a brigade combat team—is considered to be, according to the Army, the greatest technology and integration challenge it has ever undertaken. The Army started its FCS program in May 2003 without fulfilling the basic elements of a business case—that is, determining if the program's requirements and concept were valid and that the concept could be successfully developed with existing resources including proven technologies, stable design, adequate funding, and adequate time. The Army projects the FCS program will cost \$163.7 billion, which has been adjusted for inflation, but does not include key complementary programs. As a result, the program is recognized as being high risk and in need of special oversight and review. In 2006, Congress mandated that the Department of Defense (DOD) hold an FCS milestone review, essentially a “go/no-go” decision, following its preliminary design review, which is now scheduled for early 2009.

Given its cost, scope, and technical challenges, section 211 of the National Defense Authorization Act for Fiscal Year 2006 requires GAO to report annually on the FCS program.<sup>1</sup> The specific objectives of this report are to assess FCS progress in terms of (1) definition of requirements; (2) status of critical technologies, software development, and complementary programs; (3) the soundness of the acquisition strategy as it relates to design and production as well as the spin-out of capabilities to current forces; and (4) reasonableness of program costs and whether funds have been committed to complete the program as planned.

In conducting our work, we have contacted numerous DOD and Army offices. We reviewed documents pertaining to the FCS program, attended meetings at which DOD and Army officials reviewed program progress, and held discussions with key DOD and Army officials on various aspects of the program. Officials from DOD and the Army have provided us access

---

<sup>1</sup>Pub. L. No. 109-163, § 211.

---

to sufficient information to make informed judgments on the matters in this report. In addition, we drew from our body of past work on weapon systems acquisition practices. We performed our work from March 2006 to March 2007 in accordance with generally accepted government auditing standards. Appendix I further discusses our scope and methodology.

---

## Results in Brief

To date, the FCS program has spent about \$8 billion despite having significantly less knowledge—and less assurance of success—than required by best practices or DOD policy. By early 2009, enough knowledge should be available about the key elements of the FCS business case to make a well-informed decision on whether and how to proceed with the program. If significant doubts remain regarding the program's executability, DOD will have to consider alternatives to proceeding with the program as planned. Central to the go/no-go decision will be demonstrable soundness of the FCS business case in the areas of requirements, technology, acquisition strategy, and finances. Our assessment of these elements today is as follows:

*Requirements:* Progress has been made in defining requirements in greater detail, and some difficult trade-offs have been made. The Army believes that the FCS requirements are feasible, but that will not be certain until key assumptions about the performance of immature technologies and other technical risks are proven. Replacing these assumptions with knowledge is essential for completing the requirements process for the individual FCS systems, as additional performance trade-offs may be necessary.

*Technology:* The Army has made progress in maturing technologies in the past year, but major challenges remain. It assesses about 80 percent of FCS technologies to be mature—double last year's number. The Army uses a lower standard for maturity than what GAO has found to be a best practice. The current assessment was not done independently as last year's had been. A sound business case would require FCS to have had all technologies mature in 2003 when the program began. It will still take several more years to mature key technologies to that point. Current estimates of FCS software—the most in any weapon system program—are double initial estimates. The Army is attempting to incorporate a number of best practices into its development effort, and some initial increments of software have been delivered on time.

*Acquisition Strategy:* Even if all goes as planned, the FCS strategy will provide for late demonstration of performance. Similar to technologies,

---

design reviews of FCS systems will be done quite late in the program and key testing will not begin until just prior to the initial production decision. Relative to best practices, maturity of design and production will not be demonstrated until after the production decision. The Army has started to implement its plans to spin out some early FCS technologies and systems to current Army forces and that effort is expected to place more demands on FCS test resources.

*Program Costs:* FCS costs are likely to grow, which will increase the tension between the program's scope and available funds. While the Army has only slightly changed its cost estimate of \$160.7 billion since last year, independent cost estimates put costs at between \$203 billion to nearly \$234 billion. The tension between program scope and available funds has led to the Army's recent announcement to buy fewer systems and slow production rates. This will be the second restructuring in 4 years. These changes will affect program costs, but full details are not yet available.

Anticipating that further changes will need to be made to the program, we are making several recommendations to the Secretary of Defense on specific criteria that should be considered during the 2009 milestone review and the need to analyze alternatives to the program should the FCS fail to deliver needed capabilities within reasonable time frames and expected funding. In commenting on a draft of this report, DOD concurred with our recommendations.

---

## Background

The FCS concept is designed to be part of the Army's Future Force, which is intended to transform the Army into a more rapidly deployable and responsive force that differs substantially from the large division-centric structure of the past. The Army is reorganizing its current forces into modular brigade combat teams, each of which is expected to be highly survivable and the most lethal brigade-sized unit the Army has ever fielded. The Army expects FCS-equipped brigade combat teams to provide significant warfighting capabilities to DOD's overall joint military operations. The Army is implementing its transformation plans at a time when current U.S. ground forces continue to play a critical role in the ongoing conflicts in Iraq and Afghanistan. The Army has instituted plans to spin out selected FCS technologies and systems to current Army forces throughout the program's system development and demonstration phase.

As we were preparing this report, the Army made a number of adjustments to its plans for the FCS program. The revised program will no longer include all 18 systems as originally planned. The FCS family of weapons is



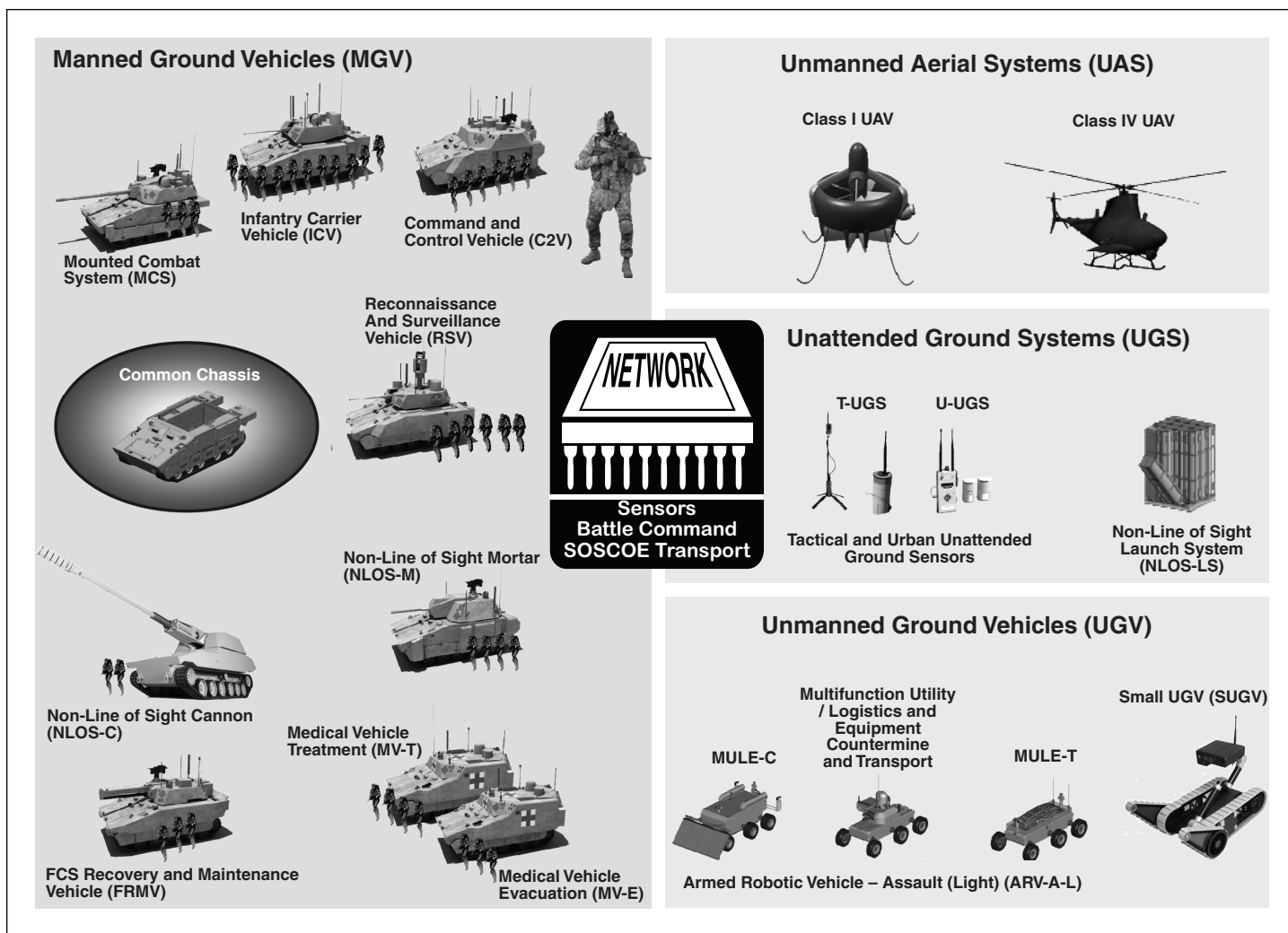
---

now expected to include 14 manned and unmanned ground vehicles, air vehicles, sensors, and munitions that will be linked by an advanced information network. The systems include

- eight new types of manned ground vehicles to replace current tanks, infantry carriers, and self-propelled howitzers;
- two classes of unmanned aerial vehicles;
- several unmanned ground vehicles; and
- an attack missile.

Fundamentally, the FCS concept is to replace mass with superior information—allowing soldiers to see and hit the enemy first rather than to rely on heavy armor to withstand a hit. This solution attempts to address a mismatch that has posed a dilemma to the Army for decades: the Army's heavy forces had the necessary firepower needed to win but required extensive support and too much time to deploy while its light forces could deploy rapidly but lacked firepower. If the Future Force becomes a reality, then the Army would be better organized, staffed, equipped, and trained for prompt and sustained land combat, qualities intended to ensure that it would dominate over evolving, sophisticated threats. The Future Force is to be offensively oriented and will employ revolutionary concepts of operations, enabled by new technology. The Army envisions a new way of fighting that depends on networking the force, which involves linking people, platforms, weapons, and sensors seamlessly together in a system-of-systems.

Figure 1: FCS's Core Systems



Source: U.S. Army.

If successful, the FCS system-of-systems concept will integrate individual capabilities of weapons and platforms, thus facilitating interoperability and open system designs. This would represent significant improvement over the traditional approach of building superior individual weapons that must be retrofitted and netted together after the fact. This transformation, in terms of both operations and equipment, is under way with the full cooperation of the Army warfighter community. In fact, the development and acquisition of FCS is being accomplished using a uniquely

---

collaborative relationship among the Army's developers, the participating contractors, and the warfighter community.

The Army has employed a management approach for FCS that centers on a lead systems integrator to provide significant management services to help the Army define and develop FCS and reach across traditional Army mission areas. Because of its partner-like relationship with the Army, the lead systems integrator's responsibilities include requirements development, design, and selection of major system and subsystem subcontractors. The team of Boeing and Science Applications International Corporation is the lead systems integrator for the FCS system development and demonstration phase of acquisition, which is expected to extend until 2017. The FCS lead systems integrator acts on behalf of the Army to optimize the FCS capability, maximize competition, ensure interoperability, and maintain commonality in order to reduce life-cycle costs. Boeing also acts as an FCS supplier in that it is responsible for developing two important software subsystems. The Army advised us that it did not believe it had the resources or flexibility to use its traditional acquisition process to field a program as complex as FCS under the aggressive timeline established by the then-Army Chief of Staff. The Army will maintain oversight and final approval of the lead systems integrator's subcontracting and competition plans. The FCS lead systems integrator originally operated under a contractual instrument called an "other transaction agreement." In 2006, the Army completed the conversion of that instrument to a more typical contract based on the Federal Acquisition Regulation. As required by section 115 of the John Warner National Defense Authorization Act for Fiscal Year 2007, we are reviewing the contractual relationship between the Army and the lead systems integrator and will be reporting on that work separately.<sup>2</sup>

---

## Elements of a Business Case

We have frequently reported on the wisdom of using a solid, executable business case before committing resources to a new product development effort. In the case of DOD, a business case should be based on DOD acquisition policy and lessons learned from leading commercial firms and successful DOD programs. The business case in its simplest form is demonstrated evidence that (1) the warfighter's needs are valid and that they can best be met with the chosen concept, and (2) the chosen concept can be developed and produced within existing resources—that is, proven

---

<sup>2</sup>Pub. L. No. 109-364, § 115 (2006).

---

technologies, design knowledge, adequate funding, adequate time, and management capacity to deliver the product when it is needed. A program should not go forward into product development unless a sound business case can be made. If the business case measures up, the organization commits to the product development, including making the financial investment.

At the heart of a business case is a knowledge-based approach to product development that is both a best practice among leading commercial firms and the approach preferred by DOD in its acquisition policies. For a program to deliver a successful product within available resources, managers should demonstrate high levels of knowledge before significant commitments are made. In essence, knowledge supplants risk over time. This building of knowledge can be described as three levels or points that should be attained over the course of a program.

- First, at program start, the customer's needs should match the developer's available resources—mature technologies, time, funding, and management capacity. An indication of this match is the demonstrated maturity of the technologies needed to meet customer needs.<sup>3</sup> The ability of the government acquisition workforce to properly manage the effort should also be an important consideration at program start.
- Second, about midway through development, the product's design should be stable and demonstrate that it is capable of meeting performance requirements. The critical design review is the vehicle for making this determination and generally signifies the point at which the program is ready to start building production-representative prototypes.
- Third, by the time of the production decision, the product must be shown able to be manufactured within cost, schedule, and quality targets and have demonstrated its reliability. It is also the point at which the design must demonstrate that it performs as expected through realistic system-level testing.

---

<sup>3</sup>Technology readiness levels (TRLs) are a way to measure the maturity of technology. According to best practices, technology is considered sufficiently mature to start a program when it reaches a readiness level of 7. This involves a system or prototype demonstration in an operational environment. The prototype is near or at the planned operational system. Appendix III lists the definitions for all TRLs.

---

A delay in attaining any one of these levels delays the points that follow. If the technologies needed to meet requirements are not mature, design and production maturity will be delayed. In successful commercial and defense programs that we have reviewed, managers were careful to develop technology separately from and ahead of the development of the product. For this reason, the first knowledge level is the most important for improving the chances of developing a weapon system within cost and schedule estimates. DOD's acquisition policy has adopted the knowledge-based approach to acquisitions. DOD policy requires program managers to demonstrate knowledge about key aspects of a system at key points in the acquisition process. Program managers are also required to reduce integration risk and demonstrate product design prior to the design readiness review and to reduce manufacturing risk and demonstrate producibility prior to full-rate production.

The FCS program is about one-third of the way into its scheduled product development. At this stage, the program should have attained knowledge point one, with a strategy for attaining knowledge points two and three. Accordingly, we analyzed the FCS business case first as it pertains to firming requirements and maturing technologies, which indicate progress against the first knowledge point. We then analyzed FCS's strategy for attaining design and production maturity. Finally, we analyzed the costs and funding estimates made to execute the FCS business case.

---

## Agency and Congressional Actions Since Our Last Report

In our previous report on the FCS program, released in March 2006, we reported that the program entered the development phase in 2003 without reaching the level of knowledge it should have attained in the pre-development phase.<sup>4</sup> The elements of a sound business case were not reasonably present, and we noted that the Army would continue building basic knowledge in areas such as requirements and technologies for several more years. We concluded that in order for the FCS program to be successful, an improved business case was needed.

The Defense Acquisition Board met in May 2006 to review the FCS program. That review approved the Army approach to spin out certain FCS technologies to current Army forces in 2008 and directed the Army to continue with yearly in-process reviews and a Defense Acquisition Board

---

<sup>4</sup>GAO, *Defense Acquisitions: Improved Business Case Is Needed for Future Combat System's Successful Outcome*, [GAO-06-367](#) (Washington, D.C.: Mar. 14, 2006).

---

meeting in the late 2008 timeframe. Performance expectations were also established for the review. During the meeting, it was noted that significant cost and schedule risk remains for the program and that reductions in scope and more flexibility in schedule are needed to stay within current funding constraints.

Also in 2006, Congress mandated that the Secretary of Defense conduct a milestone review for the FCS program, following the preliminary design review scheduled for early 2009.<sup>5</sup> Congress stated that the review should include an assessment of whether (1) the needs are valid and can be best met with the FCS concept, (2) the FCS program can be developed and produced within existing resources, and (3) the program should continue as currently structured, be restructured, or be terminated. The Congress required the Secretary of Defense to review specific aspects of the program, including the maturity of critical technologies, program risks, demonstrations of the FCS concept and software, and a cost estimate and affordability assessment and to submit a report of the findings and conclusions of the review to Congress. Additionally, Congress has required the Secretary of Defense to provide an independent cost estimate that will encompass costs related to the FCS program and a report on the estimate. The Institute for Defense Analyses is expected to deliver this analysis to Congress by April 2007.

Finally, in response to concerns over funding shortfalls and other resource issues for fiscal years 2008 to 2013, the Army has recently made a number of changes to its plans for the FCS program. Although complete details are not yet available, the Army plans to

- reduce the number of individual systems from 18 to 14 including eliminating 2 unmanned aerial vehicles;
- slow the rate of FCS production from 1.5 to 1 brigade combat team per year;
- change the total quantities to be bought for several systems; and
- reduce the number of planned spin-outs from four to three.

Full details of the Army's plans were not available at the time of this report. Based on what is known, program officials expect that the production period for the 15 brigade combat teams would be extended

---

<sup>5</sup>John Warner National Defense Authorization Act for Fiscal Year 2007, Pub. L. No. 109-364, § 214 (2006).

---

from 2025 to 2030. The initial operating capability date would also be delayed by 5 months to the third quarter of fiscal year 2015.

---

---

## Despite Progress, FCS Requirements Must Still Prove Technically Feasible and Affordable

The Army has made considerable progress in defining system-of-systems level requirements and allocating those requirements to the individual FCS systems. This progress has necessitated making significant trade-offs to reconcile requirements with technical feasibility. A key example of this has been to allow a significant increase in manned ground vehicle weight to meet survivability requirements which in turn has forced trade-offs in transportability requirements. The feasibility of FCS requirements still depends on a number of key assumptions about immature technologies, costs, and other performance characteristics like the reliability of the network and other systems. As current assumptions in these areas become known, more trade-offs are likely. At this point, the Army has identified about 70 high technical risks that need to be resolved to assure the technical feasibility of requirements.

---

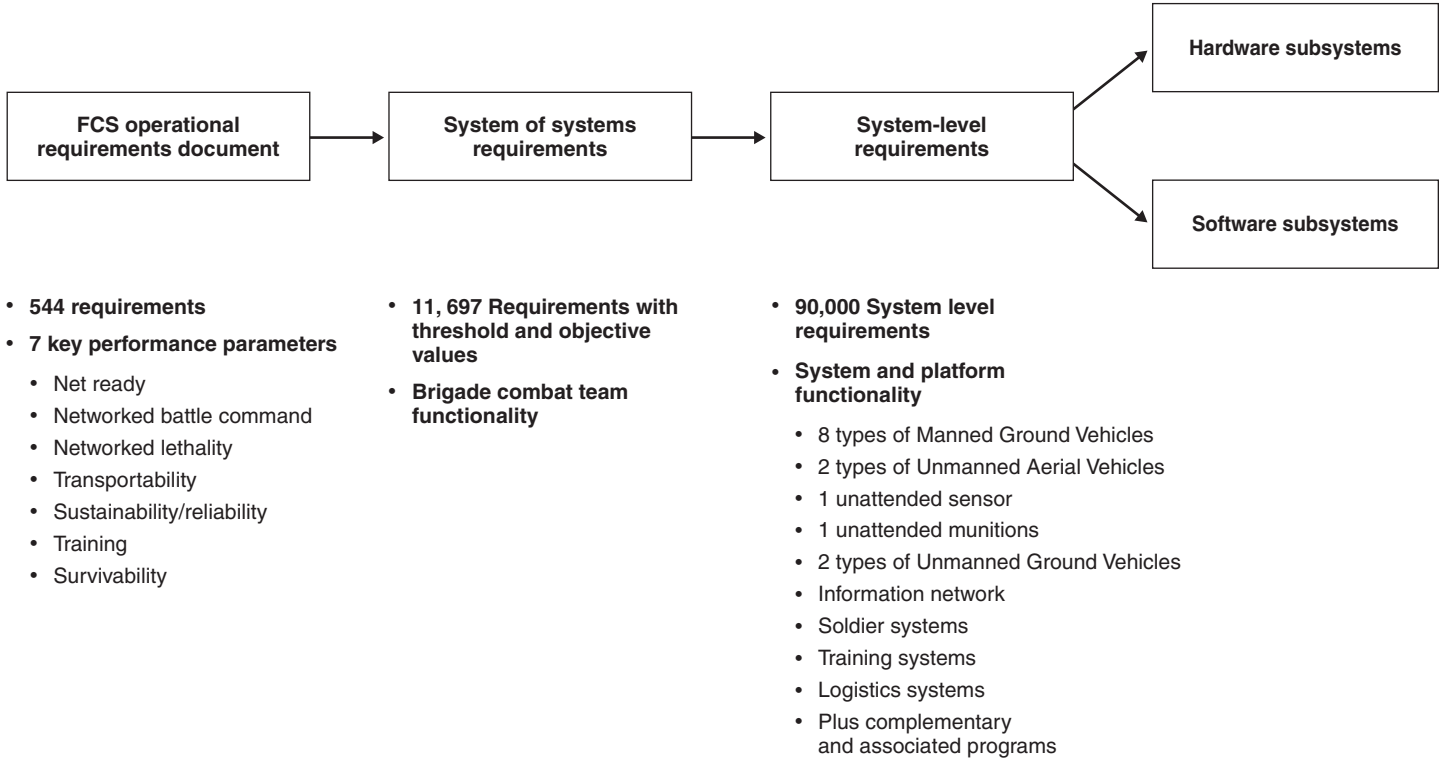
## Army Has Made Progress in Defining System-Level Requirements

The Army has defined 552 warfighter requirements for the FCS brigade combat team that are tied to seven key performance parameters: network-ready, networked battle command, networked lethality, transportability, sustainability/reliability, training, and survivability. Collectively, the Army has stated that the FCS-equipped brigade combat teams must be as good as or better than current Army forces in terms of lethality, responsiveness, sustainability, and survivability. In August 2005, the Army and the lead systems integrator translated the warfighter requirements into 11,500 more specific system-of-systems level requirements, established the functional baseline for the program, and allocated requirements to individual FCS systems. Since then, the contractors have clarified their design concepts and provided feedback on the technical feasibility and affordability of the requirements.

In an August 2006 review, the Army and its lead systems integrator reduced the number of warfighter requirements to 544, but increased the system-of-systems requirements to 11,697. Of the system-of-system requirements, 289 have “to be determined” items and 819 have open issues to be resolved. At this review, the FCS requirements were translated further down to the individual system level, totaling about 90,000. The system level requirements provide the specificity needed for the contractors to fully develop detailed designs for their individual systems. While the stages of translating requirements for FCS are typical for weapon systems, the enormous volume suggests the complex challenge that a networked system-of-systems like FCS presents.

Figure 2 illustrates how the FCS requirements are translated from the warfighter to the individual systems.

**Figure 2: Flow of FCS’s Overarching Requirements to System-Level Requirements**



Source: U.S. Army (data); GAO (analysis and presentation).

Leading up to the review, the lead systems integrator and the subcontractors identified over 10,000 “to-be-determined” items and issues to be resolved related to the flow-down of the system-of-systems requirements to the FCS system-level requirements. The “to-be-determined” items generally involve the need for the user community and the developers to come to an understanding on a way to better specify or quantify the requirement. A common issue to be resolved involves the need for compromise between the users and developers when the design solution may not be able to fully meet the initially allocated requirement. The Army and lead systems integrator plan to resolve the “to-be-



---

determined” items and issues prior to the preliminary design review in early 2009.<sup>6</sup>

The Army and lead systems integrator are also developing a network requirements document that is intended to provide end-to-end network requirements in an understandable format to inform the system-level requirements. The number of network requirements in this document has not yet been determined. However, the Army and lead systems integrator have identified about 2000 “to-be-determined” items and issues to be resolved in this area that need to be addressed and clarified. The Army and lead systems integrator expect to complete this work by the time of the preliminary design review.

#### Some Key Requirements and Design Trade-offs Have Been Made

The Army and its subcontractors have already made some trade-offs as they continue to refine their system design concepts and the FCS system-level requirements. One key trade-off came in the area of the projected weight of the manned ground vehicles and their transportability by aircraft. Originally, the manned ground vehicles were to weigh less than 20 tons so they could be carried on the C-130 aircraft. These vehicles were to be lightly armored at 19 tons and with add-on armor bringing the total vehicle weight up to about 24 tons. However, the Army and its contractor team found that this design did not provide sufficient ballistic protection. Currently, the vehicle designs with improved ballistic protection are estimated to weigh between 27 and 29 tons. At this weight, it is practically impossible to transport the vehicles on the C-130s, and they are now being designed to be transported by the larger C-17 aircraft. Illustrative of the FCS design challenges, the added weight of the vehicles could have ripple effects for the designs of the engine, suspension, band track, and other subsystems. The Army still wants vehicles to be transportable by the C-130 when stripped of armor and other equipment, so that C-130 cargo size and weight limits will still serve to constrain the design of the manned ground vehicles. As these are primarily paper and simulated designs, the potential for future trade-offs is high.

Another example involves the requirement that the manned ground vehicles be able to operate for several hours on battery power and without the engine running. Based on the analyses to date, it has been determined that current battery technologies would permit less than one hour of this

---

<sup>6</sup>The Army will hold system level preliminary design reviews leading up to the system-of-systems level preliminary design review in early 2009.

---

“silent watch” capability. The Army, lead systems integrator, and the FCS subcontractors are continuing their assessments, as is the user community, which is re-evaluating which internal manned ground vehicle subsystems may need to operate in these situations. With less demand for power, the batteries are expected to last somewhat longer. As that work concludes, the Army will be able to determine the specific level of silent watch capability it can expect for the manned ground vehicles and how best to change the operational requirements document. The Army plans to finalize this and other requirement changes and numerous clarifications by the time of the preliminary design review in early 2009.

---

**Technical Feasibility of  
System-Level  
Requirements Based on  
Numerous Assumptions**

The Army and lead systems integrator believe that most of the FCS system-level requirements are technically feasible and have decided that design work should proceed. However, as the design concepts and technologies mature, their actual performance does not necessarily match expectations, and trade-offs have to be made. To date, the Army has had to make a number of requirements and design changes that recognize the physical constraints of the designs and the limits of technology. Ideally, these trade-offs are made before a program begins. Because many technologies are not yet fully mature, significant trade-offs have been made and will continue to be necessary. The technical feasibility of FCS requirements still depends on a number of key assumptions about the performance of immature technologies, thus more trade-offs are likely as knowledge replaces assumptions. The challenge in making additional changes to requirements is at least two-fold: first is assessing the potential ripple effect of changing a requirement for one system on the thousands of other system requirements; the second is assessing the cumulative effect of numerous system level requirements changes on the overall characteristics of survivability, lethality, responsiveness, and supportability.

**Technical Feasibility  
Dependent on Addressing  
Some High Level Risks**

The Army has identified numerous known technical risks, about 70 of which are considered to be at a medium or high level. These involve the information network, characteristics like weight and reliability that cut across air and ground vehicles, and several system-specific risks. The Army is focusing management attention on these risks and has risk reduction plans in place. Nonetheless, the results of these technology development efforts will have continuing implications for design and requirements trade-offs.

---

## Network

FCS survivability depends on the brigade-wide availability of network-based situational awareness plus the inherent survivability of the FCS platforms. There is hardly any aspect of FCS functionality that is not predicated on the network, and for many key functions, the network is essential. However, the FCS program manager has stated that the Army still has a lot yet to learn on how to successfully build such an advanced information network. Some of the network medium and high level risks include:

- End-to-end quality of service on mobile ad-hoc networks. The probability is high that the FCS network will not be able to ensure that the information with the highest value is delivered to the recipients. Failure to support the warfighter in defining and implementing command intent for information management will result in substantially reduced force effectiveness, in a force that trades information for armor.
- Wideband waveform availability. The current Joint Tactical Radio System Ground Mobile Radio program continues to pose risks because its schedule is not yet synchronized with the schedule for the core FCS program or FCS spin-outs. Any schedule slip in this area could lead to further delays. This consequence will mean integrators will not have Joint Tactical Radio System hardware in sufficient quantities, capability, and function to support the FCS schedule. In addition to schedule delays this could also jeopardize the network spin-outs, experiments, and the integration of the core program requirements.
- Soldier radio waveform availability. The soldier radio waveform provides functional capabilities that are needed to support many FCS systems but may not be completed in time to support FCS development. These functional capabilities facilitate interoperability and gateway functions between the FCS family of systems. These systems are critical to FCS performance and delays of these functional capabilities will negatively impact the FCS schedule.
- Spectrum availability and usage. There is a high likelihood that more frequency spectrum is required for all of the communications needs than will be available given current design assumptions. Lack of system spectrum may force a choice to operate without critical data due to reduced data throughput, reducing mission effectiveness and leading to possible failure.

- 
- Unmanned vehicle network latency. Unmanned ground and air vehicles are completely dependent on the FCS network for command and control interaction with their soldier/operators. Inadequate response time for unmanned payload tele-operation and target designation will result in degraded payload performance and targeting when these modes are required.
  - Net-ready critical performance parameter verification and testability. The Army recognizes the risk that FCS will not be able to adequately verify and test compliance with this parameter as it relates to the Global Information Grid.<sup>7</sup> FCS is expected to have extensive connectivity with other services and agencies via the Grid. The risk is due to, among other things, the many yet-to-be-defined critical or enterprise interfaces which are being delivered in parallel. Failure to meet the net-ready testability requirements could result in, among other things, fielding delays and cost and schedule overruns.

### **Weight and Reliability**

All of the unmanned and manned ground vehicles and several other FCS systems are expected to have difficulty meeting their assigned weight targets. According to program officials, about 950 weight reduction initiatives were being considered just for the manned ground vehicles. The Army expects the FCS program to make substantial progress toward meeting these goals by the time of the preliminary design review. It is not yet clear what, if any, additional trade-offs of requirements and designs may be needed to meet the FCS weight goals.

High levels of reliability will be needed for the FCS brigade combat teams to meet their requirements for logistics footprint and supportability. Current projections indicate that many FCS systems—including the Class IV unmanned aerial vehicle, communications subsystems, and sensors—may not meet the Army's high expectations for reliability. The Army plans to address these issues and improve reliability levels by the time of the preliminary design review in 2009.

---

<sup>7</sup>The Global Information Grid is a large and complex set of programs and initiatives intended to provide internet-like capability allowing users at virtually any location to access data on demand; share information in real time; collaborate in decision making, regardless of which military service produced which weapon system; and have greater joint command of a battle situation.

---

## System-Specific Risks

The Army and lead systems integrator have also identified other medium to high risk issues that could affect the requirements and design concepts for individual FCS systems. These include:

- Class I unmanned aerial vehicle heavy fuel engine. The Class I vehicle requires a heavy fuel engine that is small in size, lightweight, and operates with high power efficiency. Such an engine does not currently exist, and no single candidate system will meet all FCS requirements without additional development. An engine design that cannot balance size and power will critically affect compliance with several key requirements.
- Lightweight track component maturation. Current band track designs do not meet mine blast requirements and may not meet the FCS durability requirement or the critical performance parameter requirements for reducing logistics footprint and reduced demand for maintenance and supply. Without enhanced mine blast resistance, vehicle mobility will be diminished, which could result in survivability impacts.
- Vehicular motion effects. There is likelihood that system design may not preclude vehicular-induced motion sickness capable of degrading the crews' ability to execute their mission. These effects may reduce the ability of the crew to perform cognitive tasks while in motion, thereby reducing operational effectiveness.
- Safe unmanned ground vehicle operations. If necessary operational experience and technology maturity is not achieved, the brigade combat teams may not be able to use these vehicles as planned. Also, if a high level of soldier confidence in the reliability and accuracy of fire control of weapons on moving unmanned ground vehicles is not achieved, the rules of engagement of these systems may be severely restricted.

### Cost Could Force Additional Requirements Trade-offs

Unit cost reduction goals have been established at the FCS brigade combat team level and have been allocated down to the individual FCS systems and major subsystems. Many FCS systems are above their assigned average cost levels, and stringent reduction goals have been assigned. In particular, the manned ground vehicles have a significant challenge ahead to meet their unit cost goals. In order to meet these goals, requirements and design trade-offs will have to be considered.

---

The Army faces considerable uncertainty about how much investment money it will have in the future for FCS. The Army has capped the total amount of development funding available for FCS, and the contract contains a provision to identify trade-offs to keep costs within that cap. Hence, if costs rise, trade-offs in requirements and design will be made to keep within the cap. Recent events provide a good example of this situation. In 2006, the Army conducted a study to determine the number and type of unmanned aerial vehicles it can and should maintain in its inventory. All four of the FCS unmanned aerial vehicles were included in that study, and a decision has recently been made to remove the Class II and III vehicles from the core program. While this will free up money for other needs, the Army will have to reallocate the requirements from those unmanned aerial vehicles to other FCS systems.

---

## Considerations for the 2009 FCS Milestone Review

As it proceeds to the preliminary design review and the subsequent go/no-go milestone, the Army faces considerable challenges in completing the definition of technically achievable and affordable system-level requirements, an essential element of a sound business case. Those challenges include

- completing the definition of all system-level requirements for all FCS systems and the information network (including addressing the “to-be-determined” items and issues to be resolved);
- completing the preliminary designs for all FCS systems and subsystems;
- clearly demonstrating that FCS key performance parameters are achievable with confidence;
- obtaining a declaration from the Army user community that the likely outcomes of the FCS program will meet its projected needs;
- clearly demonstrating that the FCS program will provide capabilities that are clearly as good as or better than those available with current Army forces, a key tenet set out by the Army as it started the FCS development program in 2003;
- mitigating FCS technical risks to significantly lower levels; and
- making demonstrable progress towards meeting key FCS goals including weight reduction, reliability improvement, and average unit production cost reduction.

---

## Army Reports Significant Progress, but Major Technological Challenges Remain

The Army has made progress in the areas of critical technologies, complementary programs, and software development. In particular, FCS program officials report that the number of critical technologies they consider as mature has doubled in the past year. While this is good progress by any measure, FCS technologies are far less mature at this point in the program than called for by best practices and DOD policy, and they still have a long way to go to reach full maturity. The Army has made some difficult decisions to improve the acquisition strategies for some key complementary programs, such as Joint Tactical Radio System and Warfighter Information Network-Tactical, but they still face significant technological and funding hurdles. Other complementary programs had been unfunded, but Army officials told us that these issues have been addressed. Finally, the Army and the lead systems integrator are utilizing many software development best practices and have delivered the initial increments of software on schedule. On the other hand, most of the software development effort lies ahead, and the amount of software code to be written—already an unprecedented undertaking—continues to grow as the demands of the FCS design becomes better understood. The Army and lead systems integrator have recognized several high risk aspects of that effort and mitigation efforts are underway.

---

## FCS Critical Technologies Are Maturing Faster Than Predicted Last Year

Last year, we reported that an independent review team assessment revealed that 18 of the program's 49 critical technologies had reached Technology Readiness Level (TRL) 6—a representative prototype system in a relevant environment.<sup>8</sup> The independent team projected that by 2006, 22 of FCS's 49 critical technologies would reach TRL 6.<sup>9</sup> The FCS program office currently assesses that 35 of 46 technologies are at or above TRL 6—a significantly faster maturation pace than predicted last year.<sup>10</sup> Figure 3 compares the readiness levels of FCS technologies over a 3-year period.

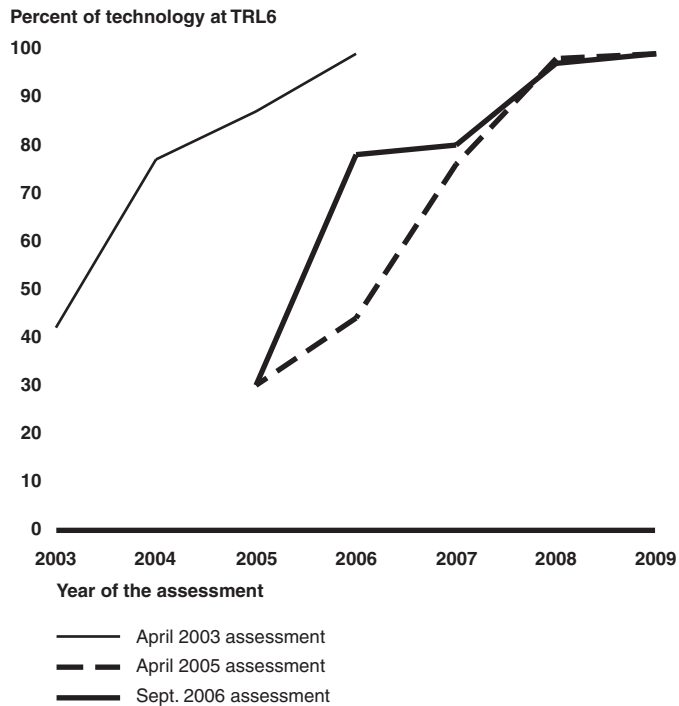
---

<sup>8</sup>A full explanation of technology readiness levels is presented in appendix III.

<sup>9</sup>Previous FCS critical technology assessments have been evaluated by an independent review team. Although the latest assessment has not been independently reviewed, the Army expects to have an independently-reviewed critical technology assessment available for the preliminary design review in early 2009.

<sup>10</sup>Since our previous report, a Critical Technology Working-Level Integrated Product Team recommended that the Army remove three critical technologies from its assessment. The team concluded that these technologies did not conform to DOD's definition of critical technologies because, in its view, the technologies did not constitute a unique or novel application.

**Figure 3: TRL 6 Projections over Time**



Source: Army (data); GAO (analysis and presentation).

Several of these technologies jumped from a TRL 4 (low-fidelity breadboard design in a laboratory environment) to a TRL 6 including cross domain guarding solutions and the ducted fan for the Class 1 unmanned aerial vehicle. The program's technology officials maintain that such a leap can be made, even though it was not anticipated by the independent assessment. They cited the ducted fan technology for small unmanned aerial vehicles as an example. This technology was largely considered immature until a single demonstration showcased the system's capabilities in demanding conditions, which convinced Army leadership that the ducted fan technology was at a TRL 6. Appendix IV lists all critical technologies, their current TRL status, and the projected date for reaching TRL 6.

However, not all of the FCS technologies are truly at a TRL 6. Two of the most important technologies for the success of manned ground vehicles and the overall FCS concept are lightweight armor and active protection. The Army has previously been more optimistic about the development pace for these technologies. However, during the past year, the Army



---

recognized that the particular solutions they were pursuing for lightweight armor were inadequate and active protection only satisfied the conditions for a TRL 5.

## Active Protection System

An active protection system is part of the comprehensive FCS hit avoidance system architecture that will protect the vehicles from incoming rounds, like rocket-propelled grenades and anti-tank missiles. The active protection system would involve detecting an incoming round or rocket propelled grenade and launching an interceptor round from the vehicle to destroy the incoming weapon. In mid-2006, the lead systems integrator (with Army participation) selected Raytheon from among numerous candidates to develop the architecture to satisfy FCS short-range active protection requirements. A subsequent trade study evaluated several alternative concepts and selected Raytheon's vertical launch concept for further development.

While the FCS program office's most recent technology readiness assessment indicates that the active protection system is at TRL 6, a 2006 trade study found that the Raytheon concept had only achieved a TRL 5. Active protection system is a vital technology for the FCS concept to be effective, and the FCS manned ground vehicles survivability would be questionable without that capability. Not only will the active protection system concept chosen need additional technology development and demonstration, but it also faces system integration challenges and the need for safety verifications. Indeed, the Army recognizes that it faces a challenge in demonstrating if and how it can safely operate an active protection system when dismounted soldiers are nearby.

## Lightweight Hull and Vehicle Armor

A fundamental FCS concept is to replace mass with superior information—that is to see and hit the enemy first rather than to rely on heavy armor to withstand a hit. Nonetheless, the Army has recognized that ground vehicles cannot be effective without an adequate level of ballistic protection. As a result, the Army has been developing lightweight hull and vehicle armor as a substitute for traditional, heavier armor. In the past year, the Army concluded that it would need additional ballistic protection and the Army Research Laboratory is continuing armor technology development to achieve improved protection levels and to reduce weight. The Army now anticipates achieving TRL 6 on the new armor formulation in fiscal year 2008, near the time of the manned ground vehicle preliminary design review. Armor will continue to be a technology as well as integration risk for the program for the foreseeable future.

---

## Technology Maturity Must Be Seen in a Broader Context

As noted above, the Army's progress in FCS technology is notable compared with the progress of previous years. This progress, however, does need to be put in a broader context. The business case for a program following best practices in a knowledge-based approach is to have all of its critical technologies mature to TRL 7 (fully functional prototype in an operational environment) at the start of product development. For the FCS, this would mean having had all technologies at TRL 7 by May 2003. By comparison, even with the progress the program has made in the last year, fewer than 35 of FCS's 46 technologies have attained a lower maturity—TRL 6—3½ years after starting product development. Immature technologies are markers for future cost growth. In our 2006 assessment of selected major weapon systems, development costs for the programs that started development with mature technologies increased by a modest average of 4.8 percent over the first full estimate, whereas the development costs for the programs that started development with immature technologies increased by a much higher average of 34.9 percent.<sup>11</sup>

FCS program officials do not accept these standards. Rather, they maintain they only need to mature technologies to a TRL 6 by the time of the critical design review which is now scheduled for 2011. According to the Army's engineers, once a technology achieves TRL 6, they are no longer required to track the technology's progress. They maintain that anything beyond a TRL 6 is a system integration matter and not necessarily technology development. Integration often involves adapting the technologies to the space, weight, and power demands of their intended environment. To a large extent, this is what it means to achieve a TRL 7. This is work that needs to be accomplished before the critical design reviews and is likely to pose additional trade-offs the Army will have to make to reconcile its requirements with what is possible from a technology and engineering standpoint. Accordingly, the FCS program has singled out several critical technologies that have been assessed at TRL 6 but yet continue to have moderate or high risk that could have dire consequences for meeting program requirements if they are not successfully dealt with. Examples include:

- High density packaged power. Current battery technology may not meet the performance levels needed to support the initial

---

<sup>11</sup>GAO, *Defense Acquisitions: Assessments of Selected Major Weapon Programs*, [GAO-06-391](#) (Washington, D.C.: Mar. 31, 2006).

---

production of FCS. Among other things, calendar life, cost, cooling methods, safety, and thermal management have not been demonstrated. The potential impacts of this risk could affect not only vehicle propulsion but also lethality and supportability.

- High power density engine. The Army has recognized that there is a risk that engine manufacturers may not have the capability to build a reliable, cost effective engine that will meet FCS requirements within the FCS program schedule. Engines have been tested that meet the power density required but not at engine power levels consistent with manned ground vehicle needs. The mitigation strategy includes engine testing to identify and correct potential engine design issues as soon as possible.
- Hull anti-tank mine blast protection. The Army recognizes that there is a probability, given the weight constraints on FCS platforms and evolving blast mitigation technology, that the FCS hull and crew restraints will not protect the crew from life threatening injury due to anti-tank blast mines equal to (or greater than) the threshold requirement. The potential consequence is that the mobility and survivability of the brigade combat team will be affected. The FCS program and Army Research Laboratory are developing an anti-tank mine kit for each manned ground vehicle to meet requirements.
- Highband networking waveform. FCS needs a high data rate capability to send sensor data and to support the FCS transit network. The Wideband Information Network-Tactical does not yet meet the performance requirements for size, weight, and power; signature management; and operational environments. There may be significant schedule and cost risk involved in getting that radio to meet the requirements. Without the high data rate capability, sensor data may not be presented in an adequate or timely fashion to perform targeting or provide detailed intelligence data to the warfighter.
- Cross-domain guarding solution. FCS needs this technology to ensure the security of information transmitted on the FCS information network. The Army recognizes that it will be difficult to obtain certification and accreditation as well as to meet the space, weight, and power and interface requirements of FCS. Failure to address these concerns in a timely manner will result in delays in fielding FCS-equipped units and additional costs.

The FCS program will continue to face major technological challenges for the foreseeable future. The independent technology assessment planned to

---

coincide with the preliminary design review in early 2009 should provide objective insights regarding the Army's progress on technology maturity and system integration issues.

---

## Army Reassessing Complementary Programs

The FCS program may have to interoperate or be integrated with as many as 170 other programs, some of which are in development and some of which are currently fielded programs. These programs are not being developed exclusively for FCS and are outside of its direct control. Because of the complementary programs' importance to FCS—52 had been considered essential to meeting FCS key performance parameters—the Army closely monitors how well those efforts will synchronize with the FCS program. However, many of these programs have funding or technical problems and generally have uncertain futures. We reported last year that the Army is reassessing the list of essential complementary programs given the multiple issues surrounding them and the budgetary constraints the Army is facing. In addressing the constrained budget situation in the 2008 to 2013 program objective memorandum, program officials said the Army is considering reducing the set of systems. When the set of complementary programs is finalized, the Army will have to determine how to replace any capabilities eliminated from the list.

Two complementary programs that make the FCS network possible, the Joint Tactical Radio System (JTRS) and the Warfighter Information Network-Tactical (WIN-T), were restructured and reduced in scope. A challenge in making changes in these programs is their individual and cumulative effects on FCS performance.

## JTRS

JTRS is a family of software-based radios that is to provide the high capacity, high-speed information link to vehicles, weapons, aircraft, sensors, and soldiers. The JTRS program to develop radios for ground vehicles and helicopters—now referred to as Ground Mobile Radio — began product development in June 2002 and the Army has not yet been able to mature the technologies needed to generate sufficient power as well as meet platform size and weight constraints. A second JTRS program to develop variants of small radios that will be carried by soldiers and embedded in several FCS core systems—now referred to as Handheld, Manpack, and Small Form Factor radios—entered product development with immature technologies and a lack of well-defined requirements. In 2005, DOD directed the JTRS Joint Program Executive Office to develop options for restructuring the program to better synchronize it with FCS

---

and to reduce schedule, technology, requirements, and funding risks.<sup>12</sup> The restructuring plan was approved in March 2006 and is responsive to many of the issues we raised in our June 2005 report.<sup>13</sup> However, the program still has to finalize details of the restructure including formal acquisition strategies, independent cost estimates, and test and evaluation plans. Further, there are still cost, schedule, and technical risks associated with the planned delivery of initial capabilities, and therefore it is unclear whether the capabilities will be available in time for the first spin-out of FCS capabilities to current forces in 2008. Fully developed prototypes of JTRS radios are not expected until 2010 or later.

## WIN-T

The Army is developing WIN-T to provide an integrated communications network to connect Army units on the move with higher levels of command and provide the Army's tactical extension to the Global Information Grid. Although the program has been successful in developing some technologies and demonstrating early capabilities, the status of its critical technologies is uncertain. As a result of an August 2005 study, the WIN-T program is being re-baselined to meet emerging requirements as well as a shift in Army funding priorities. The Army's proposal for restructuring would extend system development for about 5 years, and delay the production decision from 2006 to about 2011, while seeking opportunities to spin out WIN-T technologies both to FCS and to the current force. Despite this improvement, several risks remain for the program, and the restructuring does have consequences. Coupled with new FCS requirements, the restructure will increase development costs by over \$500 million. Critical technologies that support WIN-T's mobile ad hoc networking must still be matured and demonstrated, while the new FCS requirements will necessitate further technology development. Also, some WIN-T requirements are unfunded, and the Office of the Secretary of Defense recently non-concurred with part of the program's Technology Readiness Assessment. In order to obtain concurrence, the WIN-T program manager is updating the body of evidence material to reaffirm the technology maturity estimates.

---

<sup>12</sup> Joint Program Executive Office was established in February 2005 after Congress directed DOD to strengthen the joint management of all the JTRS program components.

<sup>13</sup> GAO, *Defense Acquisitions: Resolving Development Risks in the Army's Networked Communications Capabilities is Key to Fielding Future Force*, [GAO-05-669](#) (Washington, D.C.: June 15, 2005).

---

## Army Is Devoting Considerable Attention to Software Development, but Major Risks Need to be Addressed

The FCS software development program is the largest in DOD history, and the importance of software needed for FCS performance is unprecedented. The Army is attempting to incorporate a number of best practices into their development, and some initial increments of software have been delivered on time. However, since the program started, the projected amount of software needed for FCS has almost doubled, to 63.8 million lines of code. Further, the Army must address a number of high risk issues that could impact delivery schedules, operational capabilities, and overall FCS performance.

---

## Disciplined Approach Needed to Manage Unprecedented Amount of Software

Several numbers help illustrate the magnitude of the FCS software development effort

- 95 percent of FCS's functionality is controlled by software, particularly the network;
- 63 million lines of code are currently projected to be needed for FCS, more than 3 times the amount being developed for the Joint Strike Fighter;
- FCS will have its own operating system, like Microsoft Windows, called the System-of-Systems Common Operating Environment; and
- Over 100 interfaces or software connections to systems outside FCS will have to be developed.

Of primary importance to the success of FCS is the System-of-Systems Common Operating Environment software. This software is expected to act as the infrastructure for other FCS software. It is to standardize component-to-component communications within computers, vehicles, the virtual private networks, and the Global Information Grid, enabling interoperability with legacy Army, joint, coalition, government, and non-government organizations. Finally, it is to provide the integration framework for the FCS family of systems and enable integrated system-of-systems functionality and performance.

We have previously reported that software-intensive weapon programs are more likely to reach successful outcomes if they used a manageable evolutionary environment and disciplined process and managed by metrics.<sup>14</sup> The Army is attempting to follow such an approach to meet the

---

<sup>14</sup>GAO, *Defense Acquisitions: Stronger Management Practices Are Needed to Improve DOD's Software-Intensive Weapons Acquisitions*. [GAO-04-393](#) (Washington, D.C.: Mar. 1, 2004).

---

---

Considerable Risks Remain  
with Software Development

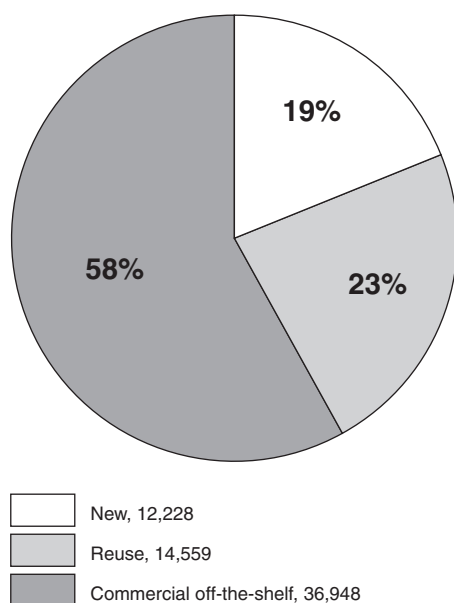
software challenges on FCS. Specifically, FCS software will be developed in four discrete stages, or blocks. Each block adds incremental functionality in eight functional areas (command and control, simulation, logistics, training, manned ground vehicles, unmanned aerial vehicles, unmanned ground vehicles, and warfighting systems). The Army and lead systems integrator are also partitioning software into at least 100 smaller, more manageable subsystems. The FCS program is also implementing scheduled and gated reviews to discipline software development and have developed a set of metrics to measure technical performance in terms of growth, stability, quality, staffing, and process.

Apart from the sheer difficulty of writing and testing such a large volume of complex code, a number of risks face the FCS software development effort. As requirements have become better understood, the number of lines of code has grown since the program began in 2003. Specifically, in 2003, the Army estimated that FCS would need 33.7 million lines of code, compared to today's estimate of 63.8 million. As the Army and its contractors learn more about the limits of technology and its design concepts, the amount and functionality to be delivered by software may change.

FCS's 63 million lines of software code can be broken down further into code that is new, reused, or commercial-off-the-shelf, as seen in figure 4.

---

**Figure 4: FCS Projected Software Lines of Code (in thousands)**



Source: Army (data); GAO (analysis and presentation).

The Army maintains that new software code presents the greatest challenge because it has to be written from scratch. Reused code is code already written for other military systems that is being adapted to FCS. Similarly, commercial-off-the shelf software is code already written for commercial systems that is being adapted to FCS. A program official told us that estimates of software code that will be reused are often overstated and the difficulty of adapting commercial software is often understated in DOD programs. This optimism translates into greater time and effort to develop software than planned. An independent estimate of reuse and commercial software has concluded that these efforts have been understated for the FCS program, which will translate into higher cost and schedule slippage.<sup>15</sup> If the independent estimate proves correct, more software development could be pushed beyond the production decision.

A foundational block of software (Build 0) has already been completed and an interim package of the System-of-Systems Common Operating Environment software was recently tested and delivered. However, as can

---

<sup>15</sup>The estimate was conducted by the Office of the Secretary of Defense's Cost Analysis and Improvement Group in support of the FCS Milestone B review from May 2003.



be seen in table 1, even if FCS stays on schedule, a portion—10 percent—of FCS software is planned to be delivered and tested after the early 2013 production decision that will limit the knowledge available to decision makers at that point.<sup>16</sup>

**Table 1: FCS Software Blocks, Percentage of Completion, and Delivery Dates**

Block	Percentage of total software completed	Delivery date
0	5	September 2005
1	30	December 2007
2	61	May 2010
3	90	October 2011
4	100	October 2013

Source: U.S. Army (data); GAO (analysis and presentation).

Currently, the Army estimates that 45 percent of the total 63 million source lines of code will have been written and tested by the early 2009 preliminary design review and 75 percent will be done by the 2011 critical design review. Although there has been no significant schedule slippage to date on the initial increments of software, both of these estimates may prove to be ambitious. Additionally, according to program officials, the most difficult part of software development is the last 10 percent.

Although the Army is attempting to implement several software best practices, there are a number of factors that may complicate those efforts. One of the leading problems in software development is the lack of adequately defined requirements. Without adequate definition and validation of requirements and design, software engineers could be coding to an incorrect design, resulting in missing functionality and errors. As we discussed earlier, the ultimate system-level requirements may not be complete until the preliminary design review in 2009. The Army acknowledges that the FCS's lack of adequate requirements and incomplete system architecture could result in software that does not provide the desired functionality or performance. This lack of top-level requirements and architecture definition also affects the accuracy of projected lines of code. Program risk charts suggest that software

<sup>16</sup>In the recent adjustments to the FCS program, the Army has moved the Milestone C decision about 5 months to early 2013. Based on the available information on the program adjustments, it is not clear if the software delivery dates have been impacted.

---

estimates could be understated by as much as 70 percent, which could impact overall schedule and performance.

The Army has identified specific aspects of FCS software development as high risk and is developing plans to mitigate the risks:

- System-of-Systems Common Operating Environment Availability and Maturity. There is a recognized risk that the software may not reach the necessary technical maturity level required to meet program milestones.
- FCS software integration performance and development. Due to the complexity, functional scope, net-centric focus, and real-time requirements for the command and control software, software integration may not yield fully functional software that performs as desired.
- Block 1 incompatible software components during integration. There are a large number of diverse groups working on software components that need to be integrated into full units. A lack of early integration process and collaboration among the suppliers represents substantial risk to rework during integration and subsequent schedule impact.
- Software estimating accuracy. To date, estimating accuracy has been hampered by changing requirements, immature architecture, and insufficient time to thoroughly analyze software subsystems sizing. The difficulties associated with accurate software estimating is an indication that complexity increases as the design is better understood and this serves to increase the level of effort.
- Software supplier integration. The unprecedented nature, volatility, and close coupling of FCS suppliers' software will frequently require various combinations of suppliers to share information and rapidly negotiate changes in their products, interfaces, and schedules. As these suppliers are traditionally wary competitors that are used to performing to fixed specifications, there are significant risks of slow and inflexible adaptation to critical FCS sources of change. Failure to do so will translate directly into missed delivery schedules, significantly reduced operational capabilities, and less dependable system performance.

---

## Considerations for the 2009 FCS Milestone Review

As it approaches the preliminary design review and the subsequent go/no-go milestone review, the Army should have made additional progress in developing technologies and software as well as aligning the development of complementary programs with the FCS program. The challenges that will have to be overcome include

- demonstrating that all critical technologies are mature to at least the TRL 6 level. This assessment should be reviewed and validated by an independent review team;
- mitigating the recognized technical risks for the FCS critical technologies, including their successful integration with other FCS subsystems and systems;
- clearly demonstrating that the risks inherent in the active protection system and the lightweight hull and vehicle armor have been reduced to low levels;
- synchronizing the JTRS and WIN-T development schedules with FCS system integration and demonstration needs for both the spinouts and core program;
- mitigating the cost, schedule, and performance risks in software development to acceptably low levels; and
- establishing the set of complementary programs that are essential for FCS's success, ensuring that they are fully funded, and aligning theirs and the overall FCS program schedules.

---

## Concurrent Acquisition Strategy Will Provide for Late Demonstration of FCS Capabilities

The FCS acquisition strategy and testing schedule have become more complex as plans have been made to spin out capabilities to current Army forces. The strategy acquires knowledge later than called for by best practices and DOD policy. In addition, knowledge deficits for requirements and technologies have created enormous challenges for devising an acquisition strategy that can demonstrate the maturity of design and production processes. Even if requirements setting and technology maturity proceed without incident, FCS design and production maturity is not likely to be demonstrated until after the production decision is made. The critical design review will be held much later on FCS than other programs, and the Army will not be building production-representative prototypes with all of their intended components to test before production. Much of the testing up to the 2013 production decision will involve simulations, technology demonstrations, experiments, and single system testing. Only after that point, however, will substantial testing of the complete brigade combat team and the FCS concept of operations occur. However, production is the most expensive phase in which to resolve design or other problems found during testing. Spin-outs,

---

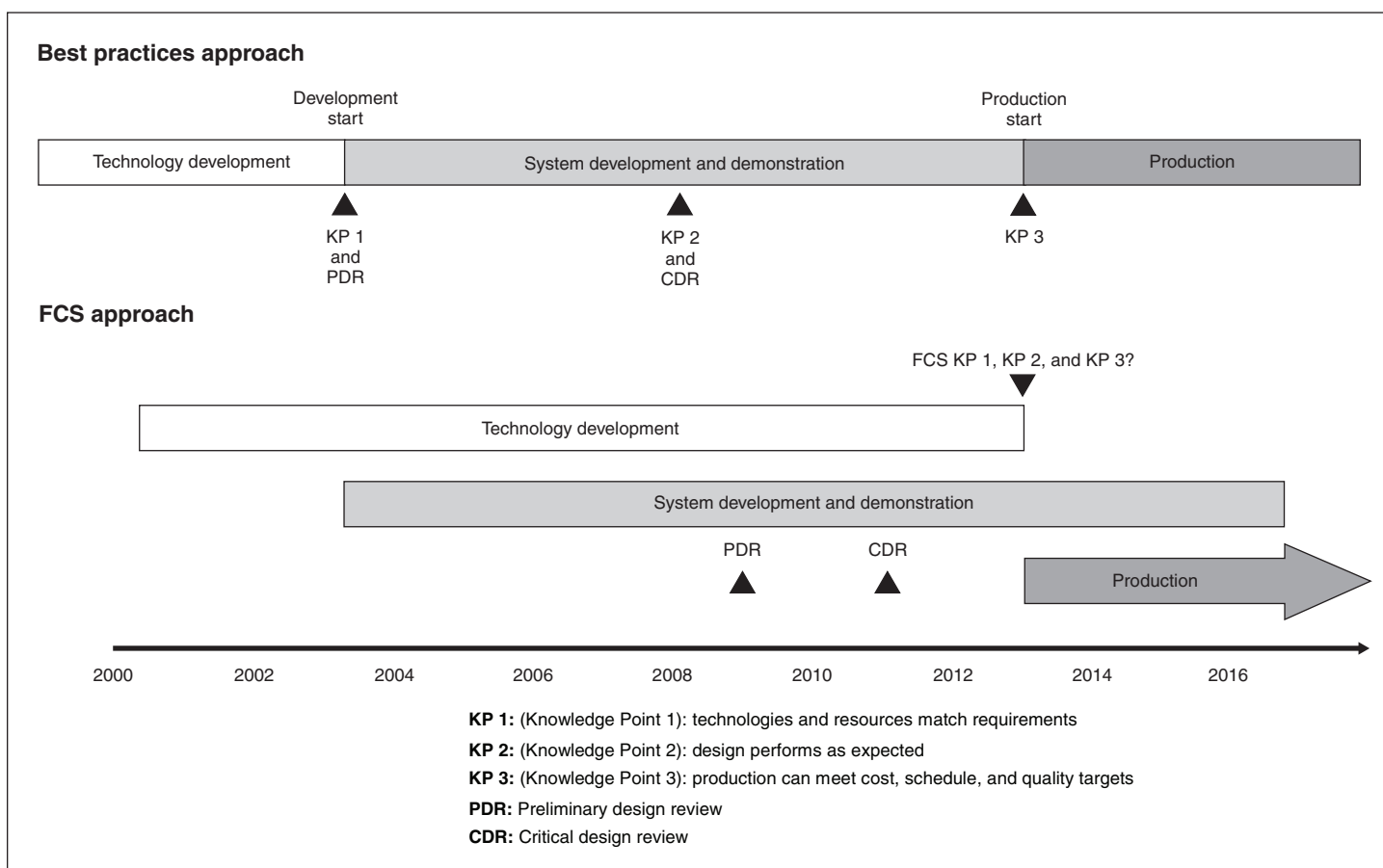
which are intended to accelerate delivery of FCS capabilities to the current force, also complicate the acquisition strategy by absorbing considerable testing resources and some tests.

---

**Acquisition Strategy Will Demonstrate Design Maturity after Production Begins**

The Army's acquisition strategy for FCS does not reflect a knowledge-based approach. Figure 5 shows how the Army's strategy for acquiring FCS involves concurrent development, design reviews that occur late in the program, and other issues that are out of alignment with the knowledge-based approach that characterizes best practices and is supported in DOD policy.

**Figure 5: Acquisition Compared with Commercial Best Practices**



Source: Army (data); GAO (analysis and presentation).

Ideally, the preliminary design review occurs at or near the start of product development. Activities leading up to the preliminary design review include, among others, translating system requirements into design specifics. Doing so can help reveal key technical and engineering challenges and can help determine if a mismatch exists between what the customer wants and what the product developer can deliver. Scheduling the preliminary design review early in product development is intended to help stabilize cost, schedule, and performance expectations. The critical design review ideally occurs midway into the product development phase. The critical design review should confirm that the system design performs as expected and is stable enough to build production-representative prototypes for testing. The building of production-representative prototypes helps decision makers confirm that the system can be

---

produced and manufactured within cost, schedule, and quality targets. According to the knowledge-based approach, a high percentage of design drawings should be completed and released to manufacturing at critical design review. The period leading up to critical design review is referred to as system integration, when individual components of a system are brought together, and the period after the review is called system demonstration, when the system as a whole demonstrates its reliability as well as its ability to work in the intended environment.

The Army has scheduled the preliminary design review in early 2009, about 6 years after the start of product development. The critical design review is scheduled in fiscal year 2011, just 2 years after the scheduled preliminary design review and 2 years before the initial FCS production decision in fiscal year 2013. This will leave little time for product demonstration and correction of any issues that are identified at that time.<sup>17</sup> This is not to suggest that the two design reviews for the FCS could have been conducted earlier but rather that commitments to build and test prototypes and begin low-rate production are scheduled too soon afterward. The timing of the design reviews is indicative of how late knowledge will be attained in the program, even if all goes according to plan. With requirements definition not being complete until at least the final preliminary design review in early 2009 and technology maturation not until after that, additional challenges will have to be addressed within the system integration phase. System integration will already be a challenging phase due to known integration issues and numerous technical risks. The best practice measure for the completion of the system integration phase is the release of at least 90 percent of engineering drawings by the time of the critical design review.

The Army is planning to have developmental prototypes of all FCS systems available for testing prior to low-rate initial production. For example, most of the manned ground vehicle prototypes are expected to be available in 2011 for developmental and qualification testing.<sup>18</sup> However, these prototypes are not expected to be production-representative prototypes and will have some surrogate components. Whereas the testing of fully

---

<sup>17</sup>The early 2009 preliminary design review and the 2011 critical design review are culminating events; system-level preliminary design reviews and critical design reviews will be conducted prior to those dates.

<sup>18</sup>The Army will have early prototypes of the non line-of-sight cannon vehicle available as early as fiscal year 2008 in order to meet congressional direction.

---

integrated, production-representative prototypes demonstrate design maturity and their fabrication can demonstrate production process maturity, neither of these knowledge points will be attained until after the initial production decision is made.

---

### System-Level Testing Compressed into Late Development and Early Production

The FCS test program is unique because it is designed to field a new fighting unit and concept of operations to the Army, not just new equipment. To help do this, the Army has incorporated a new evaluation unit, known as the Evaluation Brigade Combat Team, to help with development and testing of the FCS systems and the tactics, techniques, and procedures necessary for the unit to fight. The test effort will involve four phases during development, which examine how the program is maturing hardware and software, during development. These phases are intended as check points. The first phase has a corresponding spin-out of mature FCS capabilities to current forces.

The Army is proceeding with its plans to reduce FCS risks using modeling, simulation, emulation, and system integration laboratories. This approach is a key aspect of the Army's acquisition strategy and is designed to reduce the dependence on late testing to gain valuable insights about many aspects of FCS development, including design progress. However, on a first-of-a-kind system—like FCS—that represents a radical departure from current systems and warfighting concepts, actual testing of all the components integrated together is the final proof that the FCS system-of-systems concept works both as predicted and expected. FCS program test officials told us that while they understand the limitations involved, the use of emulators, surrogates, and simulations gives the Army a tremendous amount of early information, particularly about the system-of-systems and the network. This early information is expected to make it easier for the Army to deal with the compressed period between 2010 and 2014 and give the Army the ability to fix things quicker. As we were preparing this report, it was not clear what, if any, impact the Army's program adjustments would have on its testing and demonstration plans and schedules. Table 2 describes the key test events, as currently scheduled, throughout the FCS program.

**Table 2: Key FCS Test Event Schedule**

No.	Event	Systems	Description	Dates
1	Experiment 1.1	Ground sensors and other emulators, radio systems, and other systems	Provides early and limited assessment of abilities of selected network systems	7/2006 to 6/2007
2	Experiment 2	Command and control, ground sensors, communications, lethality enablers, and other systems	Early experiment with several FCS systems at the battalion, company, and platoon echelons	1/2008 to 1/2009
3	Spin-Out 1 Limited User Test 1	Various computer systems, ground sensors, and missile launch system	Battalion level test with current force equipment and selected systems being “spun” out to current forces	3/2008 to 4/2008
<b>Preliminary design review</b>				<b>2nd quarter fiscal year 2009</b>
<b>Defense acquisition board milestone review</b>				<b>3rd quarter fiscal year 2009</b>
4	Early Ground Vehicle Delivery	Early prototype of the non line of sight-cannon manned ground vehicle	Initial prototype with commonality with later prototypes	3rd Quarter Fiscal Year 2008
5	Integrated Mission Test 2	Integration laboratory, simulations, common operating system and other items	First system-of-systems test in integration phase 2 and indicator of network functionality	8/2009 to 11/2010
6	Aerial Vehicle	Prototype of the Class IV Fire Scout	Early prototype delivery and demonstration	3/2010
7	Limited User Test 2	Small number of unmanned aerial vehicles and a task organized platoon	Assess network maturity and capabilities of aerial vehicles in operational environment	2/2010 to 4/2010
8	Spin-Out 1 Initial Operational Test	Various computer systems, ground sensors, and missile launch system	Operational test of selected systems and their effectiveness being “spun out” to current forces	4th Quarter Fiscal Year 2010
<b>Critical design review</b>				<b>2nd quarter fiscal year 2011</b>
9	Pre-Production Prototypes Delivery	Non-Line-of-Sight Cannon and other manned ground vehicles	Pre-production prototype delivery of manned ground vehicles with common features	3rd Quarter Fiscal Year 2010 to 4th Quarter Fiscal Year 2011
10	Technical Field Test 3	Field test of the brigade combat team with prototypes	Important test that deals with maturing the network and confirms important interfaces and interoperability	10/2011 to 3/2012
11	Integrated Qualification Test 3	All manned ground vehicles and remaining unmanned ground vehicles, aerial vehicles and ground sensors	Integrated qualification tests for majority of FCS systems including pre-production representative prototypes in their core threshold configurations	8/2010 to 1/2012
12	Limited User Test 3	Some of all systems deployed in two companies with the network	Assesses the brigade combat team small unit capabilities	4/2012 to 5/2012
<b>Initial low-rate production decision</b>				<b>2nd quarter fiscal year 2013</b>
13	Production and Deployment Limited User Test	All manned ground vehicles and some unmanned systems	Complete full-up system-level tests of all systems to production standards	4th Quarter Fiscal Year 2014



No.	Event	Systems	Description	Dates
<b>Initial operating capability</b>				<b>3rd quarter fiscal year 2015</b>
14	Live Fire Test	All individual systems	Live fire tests with complete and functional systems	2014 to 2016
15	Initial Operational Test	Brigade combat team and all of the systems involved	Full spectrum operations with production representative systems in a realistic, operational live environment	3rd and 4th Quarter Fiscal Year 2016
<b>Full rate production decision</b>				<b>2nd quarter fiscal year 2017</b>
<b>Full operating capability</b>				<b>3rd quarter fiscal year 2017</b>

Source: FCS Test and Evaluation Master Plan and FCS Program Office (data); GAO (analysis and presentation).

The majority of testing through 2012 is limited in scope and is more about confidence building than demonstrations of key capabilities. Much like the overall acquisition strategy, the FCS testing plan will provide key knowledge late in the systems development phase. Early test efforts will focus on experiments and development testing of individual systems. Some early systems will be tested as part of the Army's efforts to spin out technologies to current forces, including unmanned ground sensors and the non-line-of-sight-launch system. The bulk of the developmental prototypes will not be available until 2010 and later for testing and demonstrations.

The first large scale FCS test that will include a majority of the developmental prototypes and a large operational unit will not take place until 2012, the year before production is now slated to begin. This will mark the start of the Army's testing of the whole FCS, including the overarching network and the FCS concept. For example, a limited user test in 2010 involves only a platoon and a few unmanned aerial vehicles while a similar test, in 2012, will involve two companies and developmental prototypes for each of the manned ground vehicles as well as other systems being tested at the brigade level.

Starting in 2012, several key tests will occur that should give decision makers a clearer understanding of whether the FCS system-of-systems and concept actually work as expected. By the end of 2014, production representative vehicles are expected to be available and tested in a production limited user test. Another important test is the initial operational test and evaluation in 2016, which provides the first full assessment of the entire program including all of the FCS systems, the brigade combat team, network operations, and the actual operating

---

concept. This test involves full spectrum operations in a realistic environment.

There are two major risks in the FCS testing approach: schedule compression and testing of the network. The first risk centers on the lack of time available to identify, correct, and retest for problems that come up during early testing and the second on the lack of capabilities to test an essential element of the FCS concept, the information network. Independent test officials noted that it is unclear what the Army expects from the network. With the network identified as a major risk element of the program, as well as a major risk, test officials noted that the Army needs to set benchmarks for what will be demonstrated over time. Independent testing officials have also told us that the FCS test schedule is very tight and may not allow adequate time for “test-fix-test” testing. The test and evaluation master plan recognizes this possibility by noting that within each integration phase there is only time to test and fix minor issues. More substantial problems would have to be fixed in a succeeding integration phase. Overall, testing officials are concerned that the FCS program is driven by its schedule and that the Army may rush prematurely into operational testing and perform poorly when it is too late to make cost effective corrections.

Testing of the network is critical because it must provide secure, reliable access and distribution of information over extended distances and, sometimes, when operating in complex terrain. Testing the large number of FCS sensors and the network’s ability to process the information will not be effective since test capabilities, methodologies, and expertise needed to test a tactical network of this magnitude are incomplete and insufficient. The first major test of the network and FCS together with a majority of prototypes will not take place until 2012, the year before low-rate production is now expected to begin.

The FCS program is thus susceptible to late-cycle churn, that is, the effort required to fix a significant problem that is discovered late in a product’s development. In particular, churn refers to the additional—and unanticipated—time, money, and effort that must be invested to overcome problems discovered through testing. Problems are most serious when they delay product delivery, increase product cost, or escape to the customer. The discovery of problems through testing conducted late in development is a fairly common occurrence on DOD programs, as is the attendant late-cycle churn. Often, tests of a full system, such as launching a missile or flying an aircraft, become the vehicles for discovering problems that could have been found earlier and corrected less

---

expensively. When significant problems are revealed late in a weapon system's development, the reaction—or churn—can take several forms: extending schedules to increase the investment in more prototypes and testing, terminating the program, or redesigning and modifying weapons that have already made it to the field. While DOD has accepted such problems over the years, FCS offers particular challenges, given the magnitude of its cost in an increasingly competitive environment for investment funds. Problems discovered at the production stage are generally the most expensive to correct.

---

### Spin-Outs Support the Current Force but Place More Demands on FCS Test Resources

When the Army restructured the FCS program in 2004, it revised its acquisition strategy to include a way to field various FCS capabilities—technologies and systems—to current forces while development of the core FCS program is still underway. This restructuring was expected to benefit the current forces as well as provide early demonstrations that would benefit the core FCS program. Known as spin-outs, the Army plans to begin limited low-rate production of the systems planned for Spin-Out 1 in 2009 and field those systems to current Army forces 2 years later. Leading up to the production decision in 2009 will be system development tests and a limited user test. Additional spin-outs are now planned to occur in 2010 and 2012. Using this method, the Army plans to deliver significant capabilities to the current force earlier than previously planned. Over the long-term, these capabilities include enhanced battle command capabilities and a variety of manned and unmanned ground and air platforms that are intended to improve current force survivability and operations.

Currently, FCS Spin-Out 1 involves the non-line-of sight launch system and unmanned ground sensors as well as early versions of the System-of-Systems Common Operating Environment and Battle Command software subsystems. Also included are the kits needed to interface with current force vehicles. These capabilities will be tested and validated using the Evaluation Brigade Combat Team, which will provide feedback to help refine the FCS doctrine and other matters. These systems are expected to be fielded to operational units starting in 2010, although it is unclear yet if these elements of FCS will provide significant capability to the current forces at a reasonable cost.

There are two test-related concerns with spin-outs. One is that spin-outs have complicated the FCS acquisition strategy because they focus early testing and test resources on a few mature systems that will be spun out to current Army forces. FCS program test officials told us that the primary

---

focus of the program's first integration phase will be on events supporting systems in that spin-out. It is unclear if subsequent integration phases will be similarly configured. If that were to occur, fewer overall FCS systems would be looked at and tested in each phase, and testing to evaluate how the FCS system-of-systems and concept of operations could come later than originally planned. A program official has noted that the schedule to deliver the needed hardware and software to the evaluation brigade combat team is ambitious and the schedule for tests leading up to a production decision for Spin-Out 1 is compressed. Some individual systems developmental and other testing began in 2006, but key user and operational tests will not occur until 2008, just prior to the production decision for systems in Spin-Out 1. Independent test officials have expressed concern not only over whether there will be enough time to test, fix and test again during these key tests but also whether there will be enough time to "reset" or refurbish the equipment being used from one test to another. For example, the technical field test, force development test and evaluation and pilot test, and the limited user tests for Spin-Out 1 are to be conducted back-to-back over a several month period just before the production decision. In addition, key tests including a limited user test for the non-line-of-sight launch system will take place after the Spin-Out 1 production decision. FCS program test officials have told us, however, that the program does not plan to fix and test again any problems discovered in a particular integration phase until the next integration phase. They also noted that the compressed event schedule allowed them to use the same resources and soldiers in each test.

---

## Considerations for the 2009 FCS Milestone Review

As the Army proceeds to the preliminary design review, the FCS acquisition strategy will likely continue to be aggressive, concurrent, and compressed and one that develops key knowledge later in the development process than called for by best practices. Few FCS platforms will have been tested by this point. The majority of testing and the proof of whether the systems can be integrated and work together are left to occur after prototypes are delivered starting in the next decade. The Army faces a number of key challenges as it proceeds to and beyond the preliminary design review including

- completing requirements definition and technology maturity (at least to TRL 6) to be able to complete the final preliminary design review;
- clearly demonstrating spinout capabilities prior to committing to their initial production and fielding;

- 
- completing system integration and releasing at least 90 percent of engineering drawings by the critical design review in 2011;
  - allocating sufficient time, as needed, for test, fix and retest throughout the FCS test program; and
  - allocating sufficient time to thoroughly demonstrate each FCS system, the information network, and the FCS concept prior to committing to low rate initial production in 2013.

---

## Likely Growth of FCS Costs Increases Tension between Program Scope and Available Funds

Last year, we reported that FCS program acquisition costs had increased to \$160.7 billion—76 percent—since the Army’s original estimate (figures have been adjusted for inflation.) While the Army’s current estimate is essentially the same, an independent estimate from the Office of the Secretary of Defense puts the acquisition cost of FCS between \$203 billion and \$234 billion. The comparatively low level of technology and design knowledge at this point in the program portends future cost increases. Our work on a broad base of DOD weapon system programs shows that most developmental cost increases occur after the critical design review, which will now be in 2011 for the FCS. Yet, by that point in time, the Army will have spent about 80 percent of the FCS’s development funds. Further, the Army has not yet fully estimated the cost of essential complementary programs and the procurement of spin-out items to the current force. The Army is cognizant of these resource tensions and has adopted measures in an attempt to control FCS costs. However, some of these measures involve reducing program scope in the form of lower requirements and capabilities, which will have to be reassessed against the user’s demands. Symptomatic of the continuing resource tension, the Army recently announced that it was restructuring several aspects of the FCS program, including the scope of the program and its planned annual production rates to lower its annual funding demands. This will have an impact on program cost, but full details are not yet available.

---

## New Independent Estimates Indicate Higher FCS Acquisition Costs

The Army’s official cost estimate for FCS has changed only slightly from last year’s estimate, which reflected a major program restructuring from the original estimate. In inflated dollars, the program office estimates the acquisition cost will be \$163.7 billion, up from the original 2003 estimate of \$91.4 billion. However, independent cost estimates are significantly higher, as presented in table 3.

**Table 3: Comparison of the Original Cost Estimate and Recent Cost Estimates for the FCS Program (in billions of dollars)**

	Original Army estimate	Current Army estimate	Independent cost estimate
Base year 2003 dollars	May 2003	December 2005	May 2006
Research, development, test, and evaluation	\$18.1	\$26.4	\$31.8—44.0
Procurement	\$59.1	\$92.8	\$118.7
<b>Total</b>	<b>\$77.2</b>	<b>\$119.2</b>	<b>\$150.5—162.7</b>
Inflated dollars	May 2003	December 2005	May 2006
Research, development, test, and evaluation	\$19.6	\$30.6	\$36.6—52.7
Procurement	\$71.8	\$133.1	\$166.7—181.2
<b>Total</b>	<b>\$91.4</b>	<b>\$163.7</b>	<b>\$203.3—233.9</b>

Source: U.S. Army, Office of the Secretary of Defense (data); GAO (analysis and presentation).

Recent independent estimates from the Office of the Secretary of Defense’s Cost Analysis Improvement Group indicate that FCS acquisition costs could range from \$203 billion to \$234 billion in inflated dollars. The independent estimate reflected several additional years and additional staffing beyond the Army’s estimate to achieve initial operational capability. The difference in estimates is also attributable to the Cost Analysis Improvement Group’s assessment that FCS software development would require more time and effort to complete than the Army had estimated. The independent estimate also provided for additional risks regarding the availability of key systems to support the FCS network, such as the JTRS radios. Neither the Army nor the Defense Acquisition Board has accepted the independent estimate. Program officials believe the independent estimate of research and development costs is too high because it is too conservative regarding risks.

The higher estimates of procurement costs reflect additional quantities of individual systems needed to provide full capabilities to the Brigade Combat Team. Neither the Army nor independent estimate reflects the recent decision to reduce the number of FCS systems and slow down the production rate. Prior to that decision, the Army had actually been contemplating expanding the scope of FCS to include additional Class IV unmanned aerial vehicles, additional unattended ground sensors, intelligent munitions systems, and test assets for the Army user community, as well as two new systems—a centralized controller device and a rearming module for the manned ground vehicles. This expansion

---

Soft Knowledge Base for Cost  
Estimates Portends Future  
Cost Growth

would have increased the Army's estimate to about \$208 billion, but appears obviated by the recent decision to reduce scope.

Cost estimates for any program are limited by the level of product knowledge available. All of the FCS estimates are thus limited by the relatively low level of knowledge in the FCS program today. If the FCS program had been following knowledge-based acquisition practices, its 2003 estimate would have been based on mature technologies and the current estimate would have had the benefit of a complete preliminary design review and a considerable amount of work towards the critical design review. The program's estimate would be based much more on demonstrated knowledge and actual cost versus assumptions. Instead, the current FCS estimates are built on a knowledge base without mature technologies, a preliminary design that is at least 2 years away, and a critical design review that is 3 to 4 years away. The Army must, therefore, make significant assumptions about how knowledge will develop. As experience has shown, in many DOD weapon systems, assumptions generally prove optimistic and result in underestimated costs.

As it is currently structured, the Army is planning to make substantial financial investments in the FCS program before key knowledge is gained on requirements, technologies, system designs, and system performance. Table 4 shows the annual and cumulative funding, as reported in the program's current cost estimate, and the level of knowledge to be attained each fiscal year.

The impact of the Army's recent program adjustments on the research and development funding stream were not known at the time this report was written.

**Table 4: Annual and Cumulative FCS Funding and Planned Events and Achievements**

<b>Fiscal Year</b>	<b>Percentage of funding spent to date</b>	<b>Annual research, development, test, and evaluation funding (in millions of dollars)</b>	<b>Cumulative research, development, test, and evaluation funding (in millions of dollars)</b>	<b>Planned events and achievements</b>
2003	0.5	\$165.2	\$165.2	Start of product development
2004	6.1	1701.3	1,866.5	Program restructured
2005	15.7	2929.9	4,796.4	System-of-Systems Functional Review; system-of-systems requirements stabilized; cost estimate updated
2006	26	3162.4	7,958.8	Initial system level requirements
2007	38.2	3717.7 <sup>a</sup>	11,676.5	Preliminary design work in progress
2008	50.2	3674.8	15,351.3	Most technologies reach TRL 6; final system-level requirements.
2009	61.5	3457.9	18809.2	Preliminary design review; all technologies reach TRL 6; mandated "go/no-go" review.
2010	71.9	3187.8	21,997	Limited user test 2; some prototypes available
2011	80.7	2695.4	24,692.4	Critical design review; design readiness review; all system prototypes available
2012	88.1	2253.7	26,946.1	Technologies reach full TRL 7 maturity; limited user test 3; initial system-of-systems demonstration
2013	92.7	1436.2	28,382.3	Milestone C—initial program production decision
2014	96.6	1189.4	29,571.7	Limited user test 4; full system-of-systems demonstration; fielding start brigade combat teams
2015	99.6	919.8	30,491.5	Initial operational capability
2016	100	110.6	30,602.1	Initial operational test and evaluation; full-rate production decision
2017				Full operational capability

Source: U.S. Army (data); GAO (analysis and presentation).

<sup>a</sup>Research and development funding was cut by \$254 million in the fiscal year 2007 budget.

As can be seen in table 4, through fiscal year 2007, the program will have spent about a third of its development budget—over \$11 billion. By the time of the preliminary design review and the congressionally mandated go/no-go decision in 2009, the Army will have spent about 60 percent of its FCS development budget—over \$18 billion. At that point, the program should have matured most of the critical technologies to TRL 6, and the definition of system-level requirements should be nearing completion. This is the level of knowledge the program should have achieved in 2003 before being approved for development start, according to best practices and the



---

approach preferred by DOD in its acquisition policies. The FCS critical design review is now scheduled for fiscal year 2011. By that time, the program will have spent about \$24.7 billion, or about 81 percent of its expected research and development expenditures.

The immature state of FCS technologies and the timing of its critical design review make the FCS cost estimate vulnerable to future increases. In our 2006 assessment of selected major weapon systems, we found that development costs for the programs with mature technologies increased by a modest average of 4.8 percent over the first full estimate, whereas the development costs for the programs with immature technologies increased by a much higher average of 34.9 percent.<sup>19</sup> Similarly, program acquisition unit costs for the programs with mature technologies increased by less than 1 percent, whereas the programs that started development with immature technologies experienced an average program acquisition unit cost increase of nearly 27 percent over the first full estimate. Our work also showed that most development cost growth occurred after the critical design review. Specifically, of the 28.3 percent cost growth that weapon systems average in development, 19.7 percent occurs after the critical design review.

The current cost estimates do not fully reflect the total costs to the Army. Excluded are the costs of complementary programs, such as the Joint Tactical Radio System, which are substantial. Also, the costs to procure the FCS spin-out items and needed installation kits—previously estimated to cost about \$23 billion—are not included. In fact, the procurement of FCS spinout items was not previously funded; however, as we were preparing this report, Army officials told us that in finalizing its budget plans for fiscal years 2008 to 2013, there was a decision to provide procurement funding for FCS items to be spun out to current forces. Congress recently mandated an independent cost estimate to address the full costs of developing, procuring, and fielding the FCS to be submitted by April 1, 2007.

#### Army Steps to Control FCS Program Costs

The Army has taken steps to manage the growing cost of FCS. Program officials have said that they budgeted for development risk by building \$5 billion into the original cost estimates to cover risk. They have also said that they will not exceed the cost ceiling of the development contract, but

---

<sup>19</sup>GAO, *Defense Acquisitions: Assessments of Selected Major Weapon Programs*, [GAO-06-391](#) (Washington, D.C.: Mar. 31, 2006).

---

as a result, they may have to modify, reduce, or delete lower-priority FCS requirements. However, this approach would reduce capabilities, and a lesser set of FCS capabilities may not be adequate to meet the user's expectations. Also, the Army is focusing on reducing the average unit production cost of the FCS brigade combat teams, which currently exceed the amount at which each brigade combat team is budgeted. The Army has established a glide path to reduce the unit costs; however, program officials have said they are struggling to further reduce the unit costs in many cases, particularly as a result of challenges with the manned ground vehicles. Further, any additional savings from such initiatives may not be realized until several years later into the program.

The FCS contract allows for the program to make what is called "Program Generated Adjustments" whereby any known cost overrun or increase in scope of work that would require additional funding is offset by identifying work scope that can be deleted with minimal impact to the program. Each year, the government and lead systems integrator will identify a prioritized list of candidates for capabilities that can be partially or completely deleted and its associated budget re-directed to the new work scope or to offset a cost overrun.

The Army and lead systems integrator monitor the performance of the FCS program through an earned value management system, which allows program management to monitor the technical, schedule, and cost performance of the program. As it proceeds, the Army and lead systems integrator can use the information gleaned from the earned value management system to make informed program decisions and correct potential problems early. According to earned value data, the FCS is currently tracking fairly closely with cost and schedule expectations. However, it is too early in the program for the data at this point to be conclusive. Historically, the majority of cost growth on a development program occurs after the critical design review. Further, according to program officials, due to the size and complexity of the program, coupled with an uncertain budget from year to year, detailed planning packages are only planned about 3 to 6 months in advance. While this may be unavoidable for a program as complex as FCS, the near term status of the program, as reported by the earned value management system, does not fully represent the extent of the challenges the Army still faces with FCS.

#### Funding Constraints Have Forced the Army to Restructure Its FCS Plans

FCS will command most of the Army's investment budget and thus must compete with other major investments and operations. If FCS costs increase, demands outside FCS increase, or expected funding decreases, adjustments are likely to be necessary in FCS. Last year, we reported that

---

the large annual procurement costs for FCS were expected to begin in fiscal year 2012, which was largely beyond the then-current budget planning period (fiscal years 2006 to 2011). This situation is called a funding “bow wave.” This means that more funds would be required in the years just beyond the years covered in the current defense plan that are subject to funding limits. As previously structured, the FCS program would require over \$12 billion annually in its peak procurement years. If the Army budget remains at its current levels, FCS could represent 60-70 percent of the Army’s procurement budget in those years at a time that the Army was meeting other demands, including force modularity, FCS spin-outs, complementary programs, aviation procurement, missile defense, trucks, ammunition, and other equipment.

Recently, this tension between FCS scope, costs, and competing demands has led to another set of changes in the FCS program. The FCS program manager has informed us that, in light of budget issues for the 2008 to 2013 planning period, the Army has reduced annual production rates, and plans to forego two of the originally planned unmanned aerial vehicles, among other adjustments. While this course of action is necessary to accommodate funding realities, it has other consequences, as it would increase the FCS unit costs and extend the time needed to produce and deploy FCS-equipped brigade combat teams. It would also necessitate evaluating the effects of these changes on individual system requirements and on the aggregate characteristics of lethality, survivability, responsiveness, and supportability. Details of the adjustment to the FCS program are not yet finalized; thus, we have not evaluated the full implications of the changes.

---

## Considerations for the 2009 FCS Milestone Review

By the time of the preliminary design review and the congressionally mandated go/no-go milestone in 2009, the Army should have more of the knowledge needed to build a better cost estimate for the FCS program. The Army should also have more clarity about the level of funding that may be available to it within the long term budget projections to fully develop and procure the FCS program of record. Continuing challenges include

- developing an official Army cost position that narrows the gap between the Army’s estimates and the independent cost estimate planned for that time frame. In the cost estimate, the Army should clearly establish if it includes the complete set and quantities of FCS equipment needed to meet established requirements;

- 
- ensuring that adequate funding exists in its current budget and program objective memorandum to fully fund the FCS program of record; and
  - securing funding for the development of the complementary systems deemed necessary for the FCS as well as to procure the FCS capabilities planned to be spun out to the current forces.

---

## Conclusions

The Army has been granted a lot of latitude to carry out a large program like FCS this far into development with relatively little demonstrated knowledge. Tangible progress has been made during the year in several areas, including requirements and technology. Such progress warrants recognition, but not confidence. Confidence comes from high levels of demonstrated knowledge, which are yet to come. Following the preliminary design review in 2009, there should be enough knowledge demonstrated to assess FCS's prospects for success. It is thus important that specific criteria—as quantifiable as possible and consistent with best practices—be established now to evaluate that knowledge.

At the same time, decision makers must put this knowledge in context. Specifically, if the FCS is able to demonstrate the level of knowledge that should be expected at a preliminary design review, it will be about at the point when it should be ready to begin system development and demonstration. Instead, by that time, FCS will be halfway through that phase, with only 4 years left to demonstrate that the system-of-systems design works before the planned production commitment is made. For that reason, decision makers will have to assess the complete business case for FCS. This will include demonstrative proof not only that requirements can be met with mature technologies and the preliminary design, but also that the remainder of the acquisition strategy adequately provides for demonstration of design maturity, production process maturity, and funding availability before the production decision is made.

Clearly, it is in the nation's interests for the FCS to be the right solution for the future and to be a successful development. FCS has not been an easy solution to pursue and underscores the commitment and vision of Army leadership. Nonetheless, in view of the great technical challenges facing the program, the possibility that FCS may not deliver the right capability must be acknowledged and anticipated. At this point, the only alternative course of action to FCS appears to be current Army weapons, increasingly upgraded with FCS spin-out technologies. It is incumbent upon DOD, then, to identify alternative courses of action to equip future Army forces by the time the go/no-go decision is made on FCS. Otherwise, approval to "go"

---

may have to be given not because FCS is sufficiently developed, but because there is no other viable course of action.

---

## Recommendations for Executive Action

We recommend that the Secretary of Defense establish criteria now that it will use to evaluate the FCS program as part of its go/no-go decision following its preliminary design review. At a minimum, these criteria should include

- a definition of acceptable technology maturity consistent with DOD policy for a program half way through system development and demonstration;
- determination which FCS technologies will be scored against those criteria;
- use of an independent assessment to score the FCS technologies;
- a definition of acceptable software maturity consistent with DOD policy for a program half way through system development and demonstration;
- an independent assessment to score FCS software;
- the likely performance and availability of key complementary systems;
- an assessment of how likely the FCS system-of-systems—deemed reasonable from the progress in technology, software, and design—is to provide the capabilities the Army will need to perform its roles in joint force operations (Such an assessment should include sensitivity analyses in areas of the most uncertainty.);
- a definition of acceptable levels of technology, design, and production maturity to be demonstrated at the critical design review and the production decision;
- an assessment of how well the FCS acquisition strategy and test plan will be able to demonstrate those levels of maturity;
- a determination of likely costs to develop, produce, and support the FCS that is informed by an independent cost estimate and supported by an acceptable confidence level; and
- a determination that the budget levels the Army is likely to receive will be sufficient to develop, produce, and support the FCS at expected levels of cost.

We also recommend that the Secretary of Defense analyze alternative courses of action DOD can take to provide the Army with sufficient capabilities, should the FCS be judged as unlikely to deliver needed capabilities in reasonable time frames and within expected funding levels.

---

## Agency Comments and Our Evaluation

DOD concurred with our recommendations and stated that the Defense Acquisition Board's review, aligned with the FCS program's preliminary design review in 2009, will be informed by a number of critical assessments and analyses. These include a technology readiness assessment, a system engineering assessment, an independent cost estimate, an evaluation of FCS capabilities, an affordability assessment, and ongoing analyses of alternatives that include current force and network alternatives.

We believe that these are constructive steps that will contribute to the Defense Acquisition Board review of the FCS following the preliminary design review. We note that it is important that the board's review be recognized as a decision meeting—albeit not technically a milestone decision—so that a declarative go/no-go decision can be made on FCS. Accordingly, while it is necessary that good information—such as that included in DOD's response—be presented to the board, it is also necessary that quantitative criteria that reflect best practices be used to evaluate the information. These criteria, some of which were included in our recommendations, should be defined by DOD now. For example, while FCS technologies need to be independently assessed, it is likewise important to establish what level of technology maturity is needed for a program at that stage and to evaluate the FCS technologies against that standard. This is true for software as well. In the area of cost, Army cost estimates should be evaluated against recognized standards, such as confidence levels as well as the independent cost estimate.

We had also recommended that criteria be established to serve as a basis for evaluating the FCS acquisition strategy, including what would constitute acceptable levels of technology, design, and production maturity to be demonstrated at the critical design review and the production decision. DOD did not respond to these aspects of our recommendations, but a response is important because they have to do with the sufficiency of the FCS business case for the remainder of the program. Finally, as DOD evaluates alternatives, there are several things to keep in mind. First, an alternative need not be a rival to the FCS, but rather the next best solution that can be adopted if FCS is not able to deliver the needed capabilities. Second, an alternative need not represent a choice between FCS and the current force, but could include fielding a subset of FCS, such as a class of vehicles, if they perform as needed and provide a militarily worthwhile capability. Third, the broader perspective of the Department of Defense—in addition to that of the Army—will benefit the consideration of alternatives.

---

We also received technical comments from DOD which have been addressed in the report, as appropriate.

---

We are sending copies of this report to the Secretary of Defense; the Secretary of the Army; and the Director, Office of Management and Budget. Copies will also be made available to others on request. In addition, the report will be available at no charge on the GAO Web site at <http://www.gao.gov>.

Please contact me on (202) 512-4841 if you or your staff has any questions concerning this report. Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. Other contributors to this report were Assistant Director William R. Graveline, William C. Allbritton, Noah B. Bleicher, Marcus C. Ferguson, John P. Swain, Robert S. Swierczek, and Carrie R. Wilson.

A handwritten signature in black ink that reads "Paul L. Francis". The signature is written in a cursive style with a large, stylized 'P' and 'F'.

Paul L. Francis  
Director  
Acquisition and Sourcing Management

---

*List of Committees:*

The Honorable Carl Levin  
Chairman  
The Honorable John McCain  
Ranking Member  
Committee on Armed Services  
United States Senate

The Honorable Daniel K. Inouye  
Chairman  
The Honorable Ted Stevens  
Ranking Member  
Subcommittee on Defense  
Committee on Appropriations  
United States Senate

The Honorable Ike Skelton  
Chairman  
The Honorable Duncan L. Hunter  
Ranking Member  
Committee on Armed Services  
House of Representatives

The Honorable John P. Murtha, Jr.  
Chairman  
The Honorable C. W. (Bill) Young  
Ranking Member  
Subcommittee on Defense  
Committee on Appropriations  
House of Representatives



---

# Appendix I: Scope and Methodology

---

To develop the information on the Future Combat System program's progress toward meeting established goals, the contribution of critical technologies and complementary systems, and the estimates of cost and program affordability, we interviewed officials of the Office of the Under Secretary of Defense (Acquisition, Technology, and Logistics); the Army G-8; the Office of the Under Secretary of Defense (Comptroller); the Secretary of Defense's Cost Analysis Improvement Group; the Director of Operational Test and Evaluation; the Assistant Secretary of the Army (Acquisition, Logistics, and Technology); the Army's Training and Doctrine Command; Surface Deployment and Distribution Command; the Fraunhofer Center at the University of Maryland; the Program Manager for the Future Combat System (Brigade Combat Team); the Future Combat System Lead Systems Integrator; and Lead Systems Integrator One Team contractors.

We reviewed, among other documents, the Future Combat System's Operational Requirements Document, the Acquisition Strategy Report, the Selected Acquisition Report, the Critical Technology Assessment and Technology Risk Mitigation Plans, and the Integrated Master Schedule.

We attended the FCS System-of-Systems Functional Review, In-Process Reviews, In-Process Preliminary Design Review, Board of Directors Reviews, and multiple system demonstrations. In our assessment of the FCS, we used the knowledge-based acquisition practices drawn from our large body of past work as well as DOD's acquisition policy and the experiences of other programs.

We discussed the issues presented in this report with officials from the Army and the Secretary of Defense and made several changes as a result. We performed our review from March 2006 to March 2007 in accordance with generally accepted auditing standards.

# Appendix II: Comments from the Department of Defense



ACQUISITION,  
TECHNOLOGY  
AND LOGISTICS

OFFICE OF THE UNDER SECRETARY OF DEFENSE  
3000 DEFENSE PENTAGON  
WASHINGTON, DC 20301-3000

MAR 13 2007

Mr. Paul L. Francis  
Director, Acquisition and Sourcing Management  
U.S. Government Accountability Office  
441 G Street N.W.  
Washington, D.C. 20548

Dear Mr. Francis:

This is the Department of Defense (DoD) response to the GAO draft report GAO-07-376, "DEFENSE ACQUISITIONS: Key Decisions to Be Made on Future Combat System" dated February 7, 2007 (GAO Code 120521).

The report recommends to the Secretary of Defense that specific criteria should be considered during the 2009 milestone review and alternatives to the program analyzed should FCS fail to deliver needed capabilities as expected.

The Department concurs with the GAO recommendations and our comments are enclosed. The Army's transformation effort, and in particular the FCS program, requires a disciplined, yet agile, acquisition construct. The FCS acquisition strategy, represents the Department's business case and includes periodic acquisition reviews by the Department, including a critical review subsequent to the FCS preliminary design review in 2009. Detailed technical comments were provided separately.

Sincerely,

David G. Ahern  
Director  
Portfolio Systems Acquisition

Enclosure:  
As stated



GAO DRAFT REPORT DATED FEBRUARY 7, 2007  
GAO-07-376 (GAO CODE 120521)

"DEFENSE ACQUISITIONS: KEY DECISIONS TO BE MADE ON  
FUTURE COMBAT SYSTEM "

DEPARTMENT OF DEFENSE COMMENTS  
TO THE GAO RECOMMENDATIONS

RECOMMENDATION 1: The GAO recommended that the Secretary of Defense establish criteria now that it will use to evaluate the FCS program as part of its go-no/go decision following its preliminary design review. At a minimum, these criteria should include:

- A definition of acceptable technology maturity consistent with DOD policy for a program half way through system development and demonstration.
- Determination which FCS technologies will be scored against those criteria.
- Use of an independent assessment to score the FCS technologies.
- A definition of acceptable software maturity consistent with DOD policy for a program half way through system development and demonstration.
- Use of an independent assessment to score the FCS software.
- The likely performance and availability of key complementary systems.
- A assessment of how likely the FCS system-of-systems – deemed reasonable from the progress in technology, software, and design – will provide the capabilities the Army will need to perform its roles in joint force operations. Such an assessment should include sensitivity analyses in areas of the most uncertainty.
- A definition of acceptable levels of technology, design, and production maturity to be demonstrated at the critical design review and the production decision.
- An assessment of how well the FCS acquisition strategy and test plan will be able to demonstrate those level of maturity.
- A determination of likely costs to develop, produce, and support the FCS that is informed by an independent cost estimate and supported by an acceptable confidence level.
- A determination that the budget levels the Army is likely to receive will be sufficient to develop, produce, and support the FCS at the expected levels of cost.

DOD RESPONSE: Concur. The FCS Defense Acquisition Board (DAB), aligned with the program's Preliminary Design Review, will receive a number of critical assessments to support the Department's FCS acquisition and budget decisions. These include:

- A Technology Readiness Assessment will be conducted by the Director, Defense Research and Engineering. This assessment will be informed by an independent review of the critical technologies and will evaluate the maturity of those technologies relative to program timeframe.
- A System Engineering Assessment will be conducted by Director, Systems and Software Engineering. This assessment will include an evaluation of and risks associated with the FCS acquisition strategy, test plan, software, and key complementary systems. Additionally, this assessment will evaluate the program's System Engineering Plan for reasonable exit criteria associated with the critical design review and production readiness.
- An Independent Cost Estimate will be conducted by the Cost Analysis and Improvement Group. This review will provide the likely costs to develop, produce and support the FCS.
- An assessment by the Joint Staff, using the Force Application Functional Capability Board, the Joint Capability Board, and the Joint Requirements Oversight Council will evaluate the FCS capabilities relative to its role in joint force operations.
- An affordability assessment conducted by PA&E will evaluate the cost levels to develop, produce, and support the FCS and likely Army budget levels.

RECOMMENDATION 2: The GAO recommended that the Secretary of Defense analyze alternative courses of action it can take to provide the Army with sufficient capabilities, should the FCS be judged as not being likely to deliver needed capabilities in reasonable timeframes and within expected funding levels.

DOD RESPONSE: Concur. The FCS DAB, aligned with the program's Preliminary Design Review, will be informed by ongoing analyses of alternatives that include current force and network alternatives.

# Appendix III: Technology Readiness Levels

Technology Readiness Levels (TRL) are measures pioneered by the National Aeronautics and Space Administration and adopted by DOD to determine whether technologies were sufficiently mature to be incorporated into a weapon system. Our prior work has found TRLs to be a valuable decision-making tool because they can presage the likely consequences of incorporating a technology at a given level of maturity into a product development. The maturity level of a technology can range from paper studies (TRL 1), to prototypes that can be tested in a realistic environment (TRL 7), to an actual system that has proven itself in mission operations (TRL 9). According to DOD acquisition policy, a technology should have been demonstrated in a relevant environment (TRL 6) or, preferably, in an operational environment (TRL 7) to be considered mature enough to use for product development. Best practices of leading commercial firms and successful DOD programs have shown that critical technologies should be mature to at least a TRL 7 before the start of product development.

Table 5: Technology Readiness Level Descriptions

Technology readiness level	Description	Hardware and software	Demonstration environment
1. Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties	None (paper studies and analysis)	None
2. Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.	None (paper studies and analysis)	None
3. Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Analytical studies and demonstration of non-scale individual components (pieces of subsystem).	Lab
4. Component and/or breadboard. Validation in laboratory environment	Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.	Low-fidelity breadboard. Integration of non-scale components to show pieces will work together. Not fully functional or form or fit but representative of technically feasible approach suitable for flight articles.	Lab

### Appendix III: Technology Readiness Levels

Technology readiness level	Description	Hardware and software	Demonstration environment
5. Component and/or breadboard validation in relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include “high fidelity” laboratory Integration of components.	High-fidelity breadboard. Functionally equivalent but not necessarily form and/or fit (size, weight, materials, etc.). Should be approaching appropriate scale. May include integration of several components with reasonably realistic support elements/subsystems to demonstrate functionality.	Lab demonstrating functionality but not form and fit. May include flight demonstrating breadboard in surrogate aircraft. Technology ready for detailed design studies.
6. System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology’s demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.	Prototype—Should be very close to form, fit, and function. Probably includes the integration of many new components and realistic supporting elements/subsystems if needed to demonstrate full functionality of the subsystem.	High-fidelity lab demonstration or limited/restricted flight demonstration for a relevant environment. Integration of technology is well defined.
7. System prototype demonstration in an operational environment	Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.	Prototype. Should be form, fit, and function integrated with other key supporting elements/subsystems to demonstrate full functionality of subsystem.	Flight demonstration in representative operational environment such as flying test bed or demonstrator aircraft. Technology is well substantiated with test data.
8. Actual system completed and “flight qualified” through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Flight-qualified hardware.	Developmental test and evaluation in the actual system application.
9. Actual system “flight proven” through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last “bug fixing” aspects of true system development. Examples include using the system under operational mission conditions.	Actual system in final form.	Operational test and evaluation in operational mission conditions.

Source: GAO analysis of National Aeronautics and Space Administration data.

# Appendix IV: Technology Readiness Level Ratings

FCS Critical Technologies		Last year's TRL ratings	Last year's TRL 6 projections	Latest TRL ratings	Latest TRL 6 projections	
Joint Interoperability	Software Programmable Radio					
	1	JTRS Cluster 1	5	2007	6	N/A
	2	JTRS Cluster 5	5	2007	6	N/A
	3	WIN-T	5	2007	6	N/A
	Interface and Information Exchange					
	4	Army, Joint, Multinational Interface	4	2008	6	N/A
Networked Battle Command	5	WIN-T Strategic Communication	4	2008	6	N/A
	Security Systems and Algorithms					
	6	Cross Domain Guarding Solution	4	2008	6	N/A
	7	Intrusion Detection—IP Network	4	2008	4	2008
	8	Intrusion Detection—Waveform	4	2008	4	2007
	9	Mobile Ad Hoc Networking Protocols	5	2007	6	N/A
	10	Quality of Service Algorithms	5	2007	5	2008
	11	Unmanned Systems Relay	5	2006	N/R	N/A
	Wideband Waveforms					
	12	Wideband Waveform—JTRS	5	2007	6	N/A
	13	Wideband Waveform—SRW	4	2007	6	N/A
	14	Advanced Man-Machine Interfaces	6	N/A	6	N/A
	15	Multi-Spectral Sensors and Seekers	6	N/A	6	N/A
	16	Decision Aids/Intelligent Agents	6	N/A	6	N/A
	Combat Identification					
	17	Air (Rotary Wing/UAV)—to—Ground	6	N/A	6	N/A
	18	Air (Fixed Wing)—to—Ground (Interim/Robust Solutions	N/R	N/A	N/R	N/A
	19	Ground—to—Air	N/R	N/A	6	N/A
	20	Ground—to—Ground (Mounted)	6	N/A	N/R	N/A
	21	Ground—to—Soldier	N/R	N/A	N/R	N/A
	22	Rapid Battlespace Deconfliction	5	2008	5	2008
	Sensor/Data Fusion and Data Compression Algorithms					
	23	Distributed Fusion Management	4	2007	4	2008
	24	Level 1 Fusion Engine	6	N/A	6	N/A
	25	Data Compression Algorithms	6	N/A	6	N/A
Networked Lethality	26	Dynamic Sensor—Shooter Pairing Algorithms and Fire Control	6	N/A	6	N/A
	LOS/BLOS/NLOS Precision Munitions Terminal Guidance					
	27	PGMM Precision Munitions, TG	5	2007	6	N/A
	28	MRM Precision Munitions, TG	5	2007	6	N/A

**Appendix IV: Technology Readiness Level  
Ratings**

		<b>Last year's TRL ratings</b>	<b>Last year's TRL 6 projections</b>	<b>Latest TRL ratings</b>	<b>Latest TRL 6 projections</b>
<b>FCS Critical Technologies</b>					
<b>29</b>	Excalibur Precision Munitions, TG	6	N/A	6	N/A
<b>30</b>	NLOS-LS, Terminal Guidance (TG)	6	N/A	6	N/A
<b>Aided/Automatic Target Recognition</b>					
<b>31</b>	Aided Target Recognition for RSTA	5	2007	5	2008
<b>32</b>	NLOS-LS ATR for Seekers	6	N/A	6	N/A
<b>33</b>	<b>Recoil Management and Lightweight Components</b>	6	N/A	6	N/A
<b>34</b>	<b>Distributed Collaboration of Manned/Unmanned Platforms</b>	5	2006	6	N/A
<b>35</b>	<b>Rapid Battle Damage Assessment</b>	N/R	N/A	N/R	N/A
<b>Transportability</b>					
<b>Sustainability/ Reliability</b>	<b>High-Power Density/Fuel-Efficient Propulsion</b>				
	<b>36</b> High-Power Density Engine	5	2007	6	N/A
	<b>37</b> Fuel-Efficient Hybrid-Electric Engine	6	N/A	6	N/A
	<b>38</b> <b>Embedded Predictive Logistics Sensors and Algorithms</b>	5	2009	N/R	N/A
	<b>39</b> <b>Lightweight Heavy Fuel Engine</b>	4	2007	5	2006
<b>Training</b>	<b>40</b> <b>Computer Generated Forces</b>	6	N/A	6	N/A
	<b>41</b> <b>Tactical Engagement Simulation</b>	4	2008	5	2008
<b>Survivability</b>	<b>Active Protection System</b>				
	<b>42</b> Active Protection System	5	2008	6	N/A
	<b>43</b> Threat Warning System	4-5	2009	4-5	2009
	<b>44</b> <b>Signature Management</b>	5-6	2006	6	N/A
	<b>45</b> <b>Lightweight Hull and Vehicle Armor</b>	5	2008	5	2008
	<b>46</b> <b>Health Monitoring and Casualty Care Interventions</b>	6	N/A	7	N/A
	<b>47</b> <b>Power Distribution and Control</b>	5	2006	6	N/A
	<b>Advanced Countermine Technology</b>				
	<b>48</b> Mine Detection	6	N/A	6	N/A
	<b>49</b> Mine Neutralization	6	N/A	6	N/A
	<b>50</b> Efficient Resource Allocation	6	N/A	N/R	N/A
	<b>51</b> Protection	4	2008	5	2008
	<b>52</b> <b>High-Density Packaged Power</b>	5	2008	6	N/A
	<b>Class 1 UAV Propulsion Technology</b>				
	<b>53</b> Ducted Fan	4	2006	6	N/A

Source: U.S. Army (data); GAO (analysis and presentation).

Note: N/A = Not Applicable; N/R = Not Rated



---

# Related GAO Products

---

*Defense Acquisitions: Improved Business Case Key for Future Combat System's Success*, [GAO-06-564T](#). Washington, D.C.: April 4, 2006.

*Defense Acquisitions: Improved Business Case is Needed for Future Combat System's Successful Outcome*, [GAO-06-367](#). Washington, D.C.: March 14, 2006.

*Defense Acquisitions: Business Case and Business Arrangements Key for Future Combat System's Success*, [GAO-06-478T](#). Washington, D.C.: March 1, 2006.

*DOD Acquisition Outcomes: A Case for Change*, [GAO-06-257T](#). Washington, D.C.: November 15, 2005.

*Force Structure: Actions Needed to Improve Estimates and Oversight of Costs for Transforming Army to a Modular Force*, [GAO-05-926](#). Washington, D.C.: September 29, 2005.

*Defense Acquisitions: Resolving Development Risks in the Army's Networked Communications Capabilities is Key to Fielding Future Force*, [GAO-05-669](#). Washington, D.C.: June 15, 2005.

*Defense Acquisitions: Future Combat Systems Challenges and Prospects for Success*, [GAO-05-428T](#). Washington, D.C.: March 16, 2005.

*Defense Acquisitions: Future Combat Systems Challenges and Prospects for Success*, [GAO-05-442T](#). Washington, D.C.: March 16, 2005.

*NASA's Space Vision: Business Case for Prometheus 1 Needed to Ensure Requirements Match Available Resources*, [GAO-05-242](#). Washington, D.C.: February 28, 2005.

*Defense Acquisitions: The Army's Future Combat Systems' Features, Risks, and Alternatives*, [GAO-04-635T](#). Washington, D.C.: April 1, 2004.

*Defense Acquisitions: Assessments of Major Weapon Programs*, [GAO-04-248](#). Washington, D.C.: March 31, 2004.

*Issues Facing the Army's Future Combat Systems Program*, [GAO-03-1010R](#). Washington, D.C.: August 13, 2003.

*Defense Acquisitions: Army Transformation Faces Weapon Systems Challenges*, [GAO-01-311](#). Washington, D.C.: May 2001.

---

**Related GAO Products**

---

*Best Practices: Better Matching of Needs and Resources Will Lead to Better Weapon System Outcomes*, [GAO-01-288](#). Washington, D.C.: March 8, 2001.

---

## GAO's Mission

The Government Accountability Office, the audit, evaluation, and investigative arm of Congress, exists to support Congress in meeting its constitutional responsibilities and to help improve the performance and accountability of the federal government for the American people. GAO examines the use of public funds; evaluates federal programs and policies; and provides analyses, recommendations, and other assistance to help Congress make informed oversight, policy, and funding decisions. GAO's commitment to good government is reflected in its core values of accountability, integrity, and reliability.

---

## Obtaining Copies of GAO Reports and Testimony

The fastest and easiest way to obtain copies of GAO documents at no cost is through GAO's Web site ([www.gao.gov](http://www.gao.gov)). Each weekday, GAO posts newly released reports, testimony, and correspondence on its Web site. To have GAO e-mail you a list of newly posted products every afternoon, go to [www.gao.gov](http://www.gao.gov) and select "Subscribe to Updates."

---

## Order by Mail or Phone

The first copy of each printed report is free. Additional copies are \$2 each. A check or money order should be made out to the Superintendent of Documents. GAO also accepts VISA and Mastercard. Orders for 100 or more copies mailed to a single address are discounted 25 percent. Orders should be sent to:

U.S. Government Accountability Office  
441 G Street NW, Room LM  
Washington, D.C. 20548

To order by Phone: Voice: (202) 512-6000  
TDD: (202) 512-2537  
Fax: (202) 512-6061

---

## To Report Fraud, Waste, and Abuse in Federal Programs

Contact:

Web site: [www.gao.gov/fraudnet/fraudnet.htm](http://www.gao.gov/fraudnet/fraudnet.htm)

E-mail: [fraudnet@gao.gov](mailto:fraudnet@gao.gov)

Automated answering system: (800) 424-5454 or (202) 512-7470

---

## Congressional Relations

Gloria Jarmon, Managing Director, [JarmonG@gao.gov](mailto:JarmonG@gao.gov) (202) 512-4400  
U.S. Government Accountability Office, 441 G Street NW, Room 7125  
Washington, D.C. 20548

---

## Public Affairs

Paul Anderson, Managing Director, [AndersonP1@gao.gov](mailto:AndersonP1@gao.gov) (202) 512-4800  
U.S. Government Accountability Office, 441 G Street NW, Room 7149  
Washington, D.C. 20548